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of the
American Association *of* Petroleum Geologists

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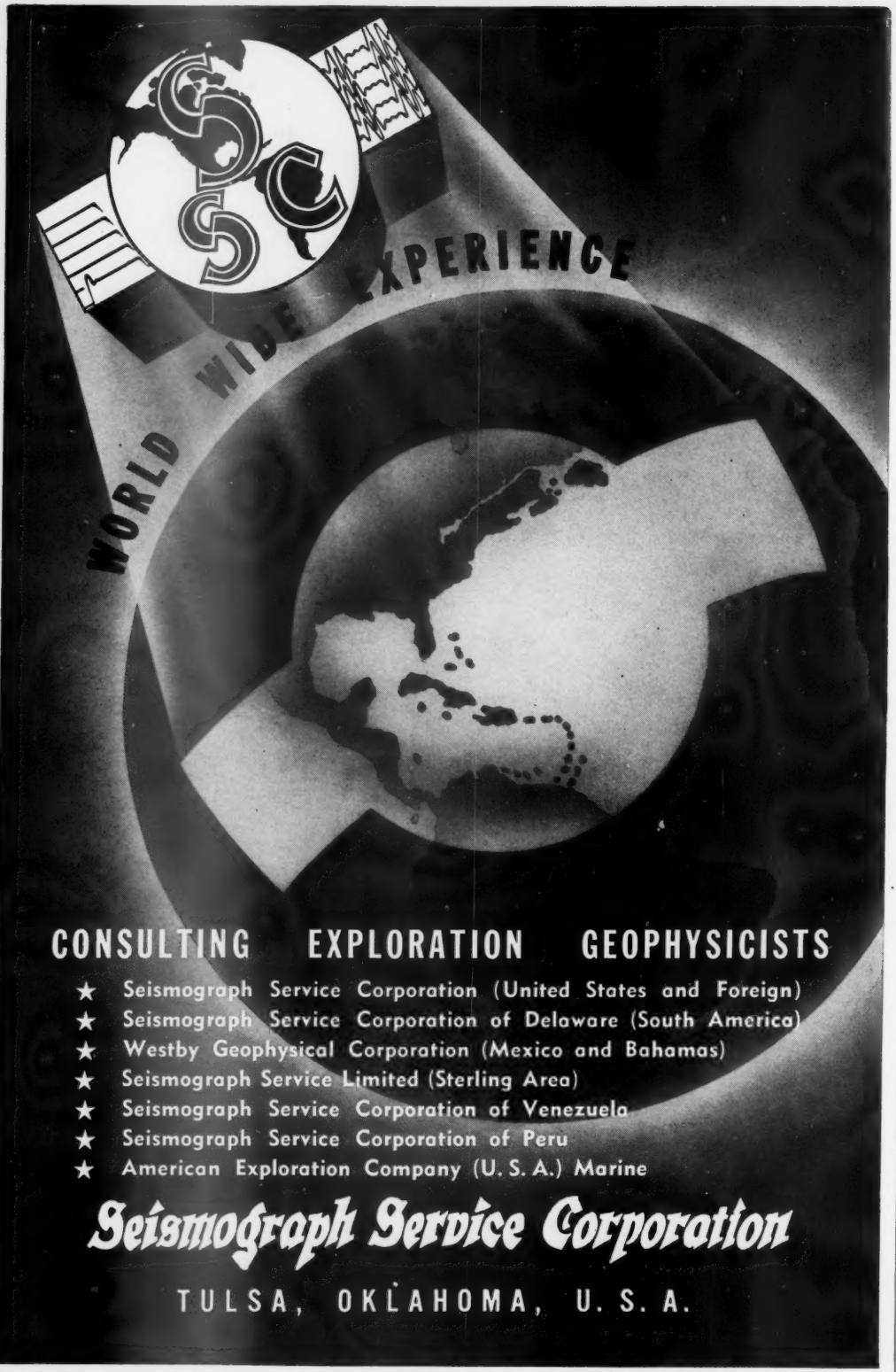
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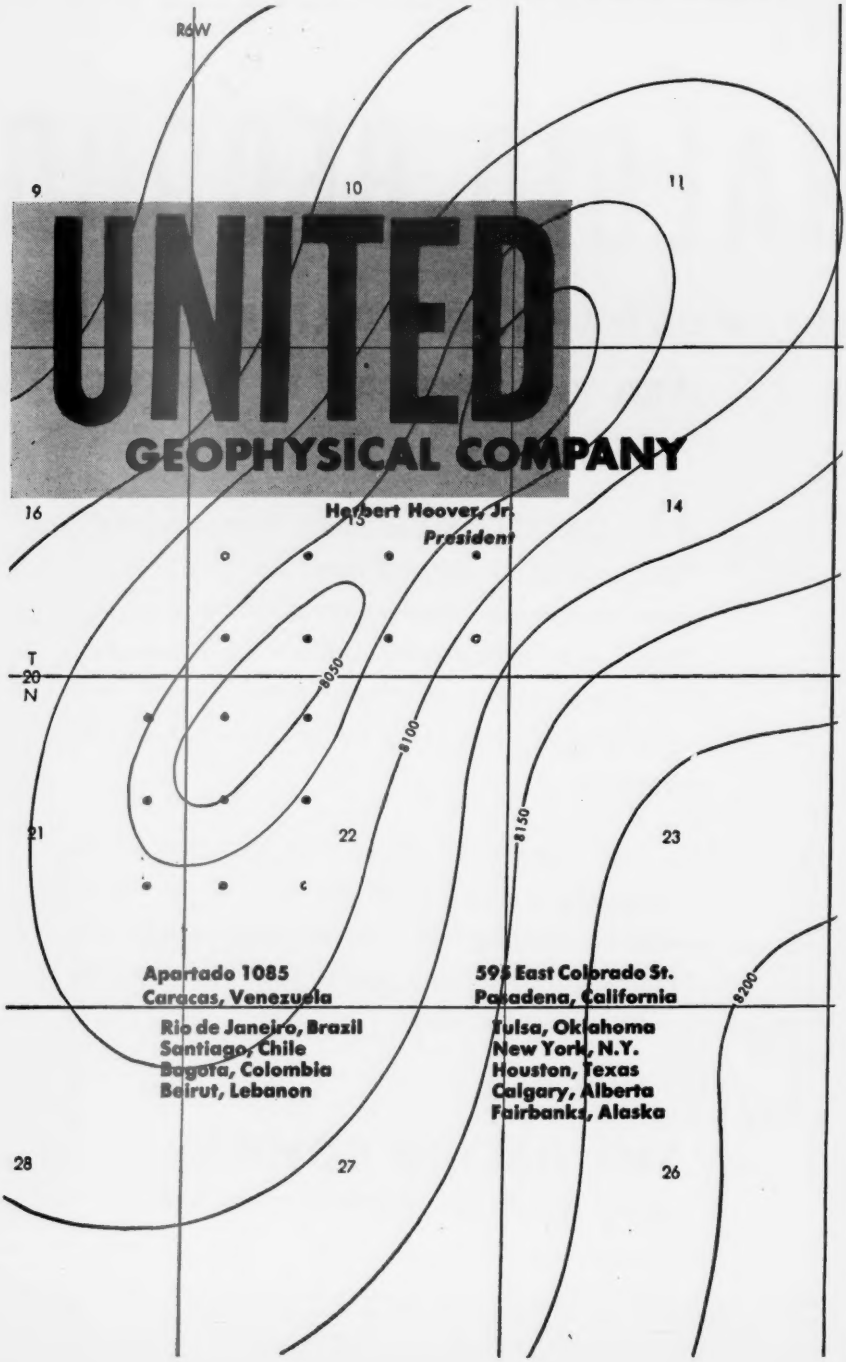
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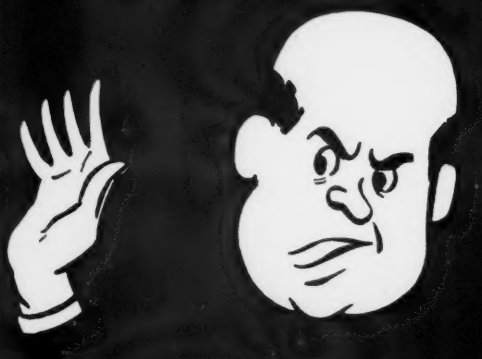

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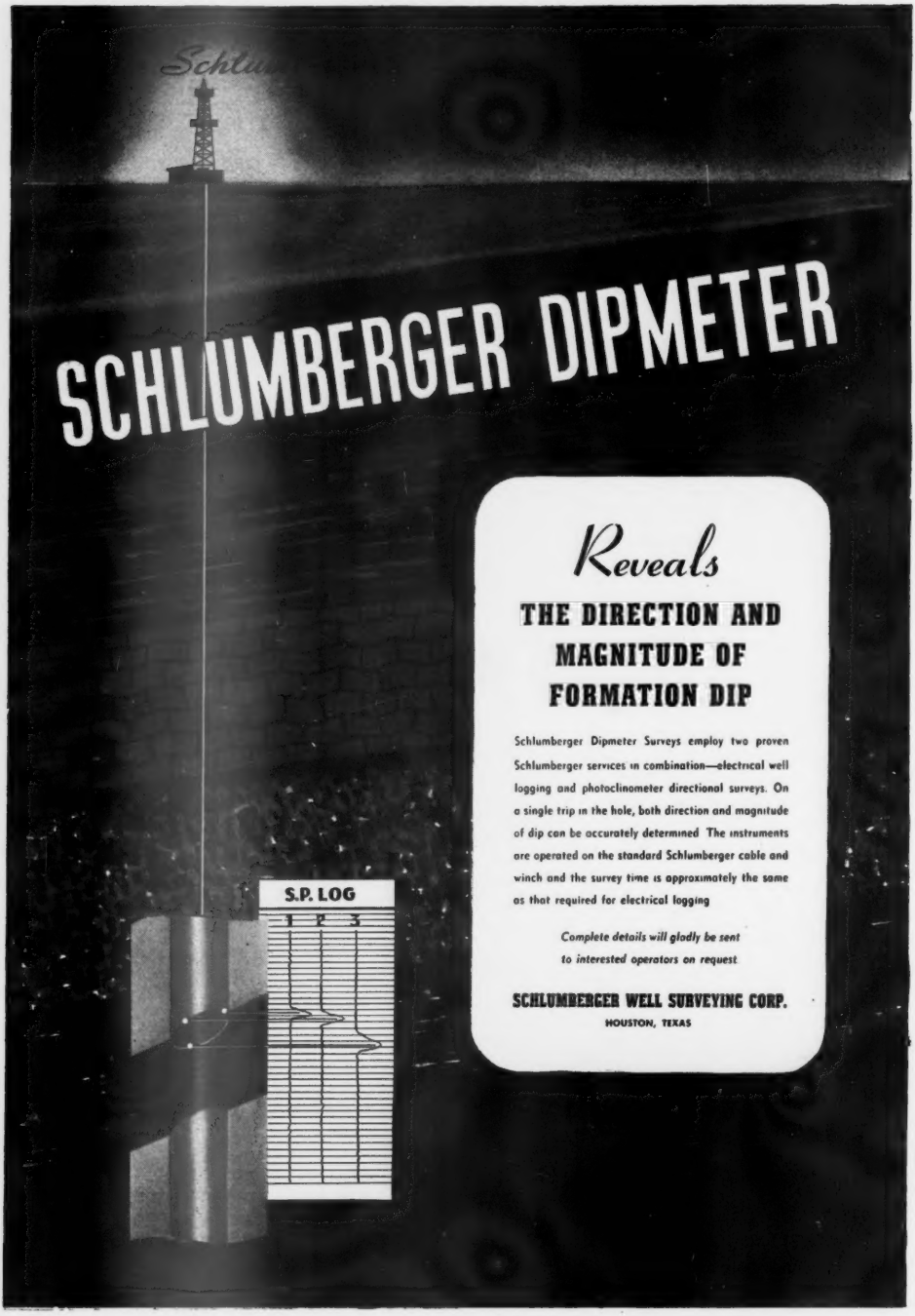
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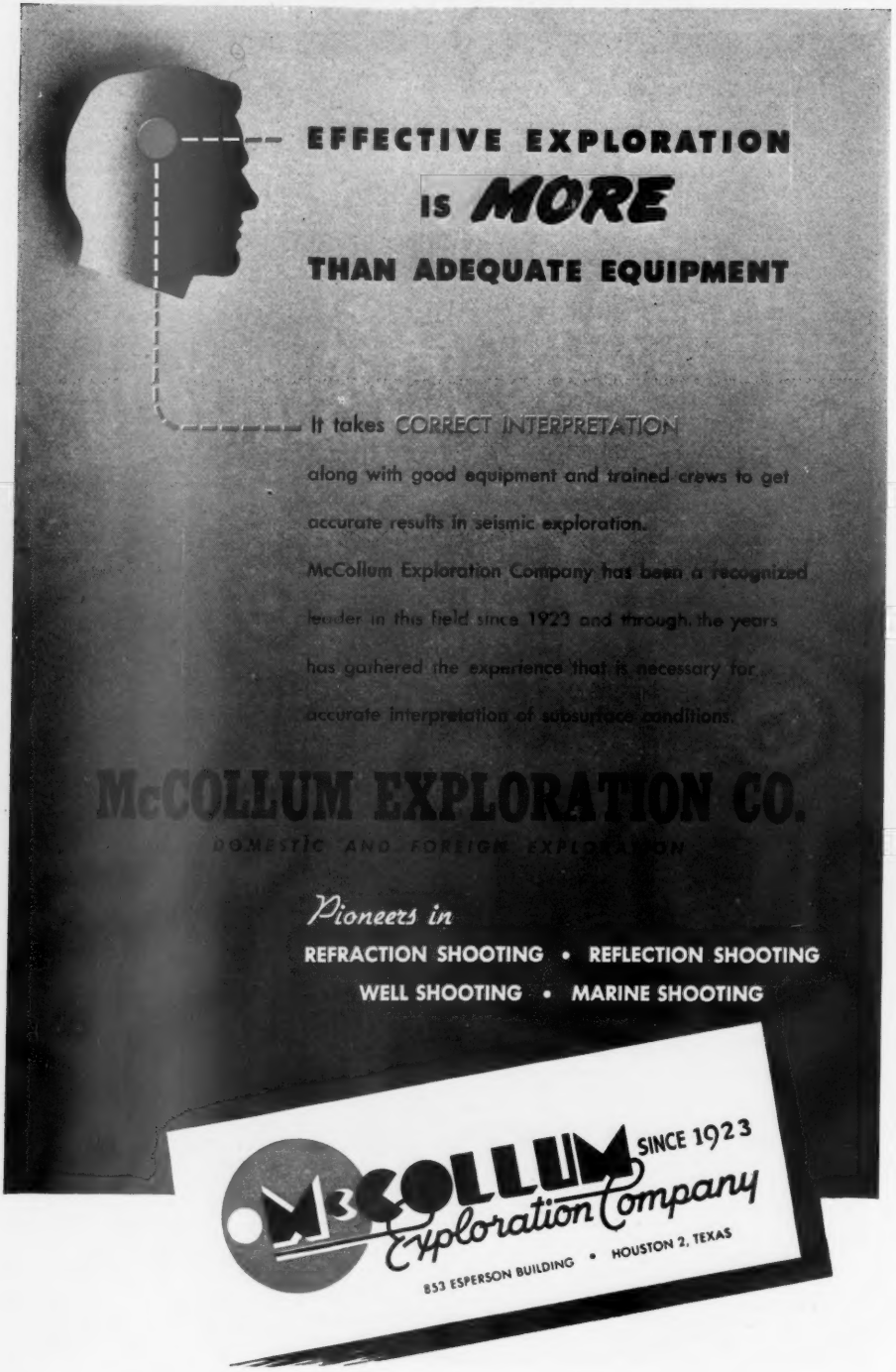
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BULLETIN
of the
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SEPTEMBER, 1948

THE GEOLOGIST IN UNIFORM: WORLD WAR II[1]

DAVID M. DELO[2]
Washington, D. C.

ABSTRACT

A study of the utilization of scientists and engineers who served in the Armed Forces during World War II has been made cooperatively by a number of the major scientific societies and the Armed Services. As a part of this study approximately 7,000 questionnaires were circulated by the American Association of Petroleum Geologists and the Geological Society of America. Replies totalling 3,142 were received and were analyzed by the Scientific Manpower Section, Research and Development Group, of the General Staff. Of these, 614 respondents reported military service in World War II. Approximately 50 per cent reported some technical utilization of their training or background while in uniform.

Analysis of all fields reveals certain general conclusions equally applicable to geology. Hence, the probable reasons for incomplete technical utilization of geologists in uniform may be generalized into the following categories: (1) lack of liaison between organized geology and the Armed Services prior to World War II; (2) consequent lack of understanding by the Services of the useful applications of geology (geologists) to military activities at both operational and planning levels; (3) the relatively small number of purely technical Service jobs as compared with the number of scientists who entered the Services; (4) an unrealistic national draft policy which, in relation to scientists, failed to operate in terms of the technical requirements of the nation as a whole; (5) necessary inflexibility of military organization and functions during a period of hostilities; (6) often unrealistic classification and assignment practices; (7) partial failure of the pre-war reserve officer system as it applied to the professional scientist.

Responsibility for the application of modern geologic techniques to military problems is equally the function of organized geology and the Armed Services. A program of continual liaison between organized geology and the Armed Services is therefore necessary. In this technological age, national defense can not be adequate without an effective arrangement of this type.

Any program to allow adequate planning during peace, and effective utilization of the Nation's technical manpower in event of any emergency, must pre-suppose cooperative and realistic long-range supply and demand studies and centralized control of technical manpower integrated with over-all technical needs.

INTRODUCTION

During 1947, at the request of the Research and Development Group, General Staff, United States Army, the American Association of Petroleum

[1] Read before the Association at Denver, April 28, 1948. Manuscript received, May 17, 1948. Published by permission of the Department of the Army. The opinions, conclusions and recommendations expressed in this paper are those of the writer and do not necessarily reflect official policy of the Department of the Army.

[2] Chief, Scientific Manpower Section, Research and Development Group, Logistics Division, General Staff, United States Army.

Geologists and the Geological Society of America conducted a survey of the activities of geologists during World War II. The purpose of this study was to determine the extent to which the training and competence of geologists were utilized by the Armed Services during the years of hostilities (1942–1945) and if possible to evaluate the factors which governed their use. This paper represents a summary of the findings from this survey, including statistical tabulations; a summary of opinions of the respondents concerning future use of geologists during national emergency; and a policy analysis of the appropriate relationship between organized geology and the national defense.

The survey was a cooperative venture. The societies prepared and circulated questionnaires to their members and those of affiliated societies; the Adjutant General's Office prepared the IBM tabulation; the Scientific Manpower Section, Research and Development Group, General Staff, prepared a report and a summarization of the opinions of the respondents as to adequate means of inspiring the effective application of geology (and geologists) to our defense should another national emergency occur.

REASONS FOR SURVEY

It is trite to state that the recent war made unprecedented use of the technological resources of the combatants. Fields of technology hitherto without apparent relation to defense activities abruptly assumed extreme military significance. Just as World War I was called a "chemists' war," so World War II became a "physicists' war" to the popular press. Radar, V–T fuses, and the atomic bomb were spectacular results of the physicists' researches. But behind the airplane which carried the atomic bomb; behind the ship which prowled the mid-night reaches of the Pacific by means of radar; behind the steel barrels of the guns which fired proximity fuses to the confusion of the enemy; in fact, behind the entire war effort, was a bulwark of natural resources—oil, iron, bauxite, coal, uraninite, and many others. It was the use of enormous quantities of these materials, fully as much as the ingenuity of the physicist, the chemist, or the engineer, which made victory possible; and it was the civilian geologist who found these resources. *Thus any modern war is basically a geologists' war.* More than ever, future defense of the nation will depend on the effectiveness of both civilian and military geological work in peace as well as war. Effective national defense in the 20th century will require optimum efficiency in the application of all our national resources, whether they be material or human.

In view of these circumstances, it was deemed necessary to evaluate the utilization of our scientific manpower resources in the past in order to plan effectively for the future. Furthermore, we might in this way discern the inhibiting circumstances which prevented full utilization, and so correct them. It was also a means to evaluate realistically many extreme statements concerning the misuse of scientific manpower by the Armed Services; and finally, to gain valuable information concerning the civilian contributions of many scientists who did not

wear a uniform. It is hoped that the organized geological societies will see fit to continue this study and that a comprehensive historical analysis of the role of geologists in every facet of the late war will be prepared at an early date.

SURVEY

Late in 1946, through initiative furnished by the then Research and Development Division of the General Staff, an unofficial interagency committee was formed to study the problems attendant on future mobilization and use of scientific manpower (scientists and engineers) on a national scale. Represented on the committee were the then War Department, Navy Department, National Research Council, Joint Research and Development Board, and President's Scientific Research Board. A representative of the National Security Resources Board has since been added.

The committee believes that intelligent planning for the future can be based only on adequate analysis of the past. The first major task, therefore, was (1) to evaluate the use of scientific manpower in uniform during the late war, and (2) to analyse the factors which governed this utilization. Cooperation was secured from major societies representing Engineering, Mathematics, Physics, Biology, Psychology, Chemistry, Geography, and Geology. A questionnaire was prepared for geologists through collaboration between representatives of the A.A.P.G., G.S.A., and U.S.G.S., closely following a pattern used in the first of these surveys by the American Chemical Society. Similar questionnaires were mailed eventually by thirty or more societies to approximately 134,000 scientists and engineers. Approximately 70,000 responded, more than 15,000 of whom had experienced military service.

Through the splendid cooperation received from the staffs and committees of the A.A.P.G. and G.S.A., approximately 7,100 questionnaires were mailed to members of these and affiliated societies. About 45 per cent responded, of whom 614 had experienced military service. This represents about one-fifth of the respondents.

Statistical analysis of the coded questionnaires was carried out by the Strength Accounting Branch of the Adjutant General's Office. Tabulations were summarized according to a pattern agreed on as essentially uniform for all societies, so as to simplify summarization of all data from the entire survey.

A copy of the questionnaire is included as part of the present paper (Fig. 1). It is to be noted that a few questions are not self-coded. These include one which specifies foreign areas with which the respondent may be geologically familiar. It is hoped that study of these answers by the societies will yield valuable information. The last two questions were also uncoded. One of these dealt with the respondent's military assignments; the other with his *opinion* as to (a) his effectiveness as a geologist in the Armed Services and (b) his suggestions as to procedures or mechanisms which should be established to insure optimum utilization of scientific manpower in any future national emergency.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
SURVEY OF GEOLOGICAL WORK 1942-1946

(June, 1947)

A careful study is being made of the use of geologists in World War II. The results of this survey will be utilized by the geological societies in their relations with the Federal Government, by the National Research Council, and by the armed services. We feel that this information will contribute materially to better planning for allocation of technical personnel should there be another national emergency. We concur heartily in the need for better planning and urge you to **fill out and return promptly** this questionnaire.

The Geological Society of America has canvassed its membership and that of associated societies. The A.A.P.G. is co-operating similarly by mailing to its membership and that of the S.E.P.M. Please overlook any duplications that may ensue.

Use enclosed addressed envelope for your return of this sheet.

1. NAME .....

2. ADDRESS .....

3. SEX: Male ..... 1 FEMALE ..... 2 DATE OF BIRTH .....
(Circle one and only one of these two code numbers)

4. FORMAL EDUCATION IN GEOLOGICAL SCIENCES: Indicate below the highest educational level reached by you in geological sciences (exclude honorary degrees)

	Doctor	Master	Incomplete Grad Tng	Bachelor	Incomp. Col Tng	No Col Tng
Geological sciences	1	2	3	4	5	6

(Circle one and only one of these six code numbers)

FORMAL EDUCATION IN A NON-GEOLOGICAL FIELD: If you received education in a field other than geology, circle below the highest education level reached by you (exclude honorary degrees).

Doctor ..... 1 Master ..... 2 Bachelor 3
Incomplete college ..... 4 None 5

5. FORMAL EDUCATION SINCE FEBRUARY 1, 1942: Circle appropriate numbers for education received since Feb. 1, 1942:

Doctor ..... 1 Bachelor ..... 3 None 5
Master ..... 2 College work—no degree 4

6. EXPERIENCE:

a. Present work status: (Circle one)

College or university 1
Economic geology (non-gov't) 2
Student 6
Present annual salary $ .....
(reply optional)
Gov't or state agency (name) 4
Military service 5
Unemployed 9
Retired 8

b. Principal type of work in which engaged between Feb. 1, 1942 and Sept. 1, 1945:
(Circle only one)

College or university 1
Gov't or state agency 2
Economic geology (non-gov't) 5
Student 6
Military service 7
Retired 8

c. If, during the period Feb. 1, 1942 to Sept. 1, 1945, you engaged in work you consider to be significant, in addition to that indicated in 6(b), circle one of the following:

College or university 1
Gov't or state agency 2
Student 6
Economic geology (non-gov't) 5
Military service 7

d. Principal experience prior to February 1, 1942:

Name of Organization	Inclusive dates	Descriptive title of work

e. Experience from February 1, 1942 to date:

Name of Organization	Inclusive dates	Descriptive title of work

(Over)

FIG. 1

Countries, states, provinces, Departments or Territories outside Continental U.S. in which Geological work has been done since 1942:

Political Division or Sub-division	R (Reconnaisance) D (Detail)	Type of Geol. work pursued i.e. structural	Nos. Mos. Spent	Lical Language learned (yes - no)

g. If now a student, state courses, degree anticipated and length of time you expect to continue your studies:

h. Specific experience, if any, as civilian with Military Depts. (Scientific Consultant, Technician, Technical Representative, etc.) Specific branch of service (SigC, QMC, etc.) and include comments deemed desirable (use separate page if necessary).

7. SELECTIVE SERVICE EXPERIENCE:

a. Indicate your draft history since the passage of the Selective Service Act by circling the number for all items which have at any time applied in your case.

1 Deferred for occupation
2 Deferred for physical reasons
9 Deferred for age
3 Deferred for any other reason
9 Never deferred

IF YOU WERE NOT IN THE ARMED SERVICE, DO NOT ANSWER THE REMAINDER OF THIS QUESTIONNAIRE

8. METHOD OF ENTRY INTO SERVICE: (Circle one)

Draft 1 — Voluntary Enlistment 2
From Reserve 3 — Direct Commission 4

9. ARM OF SERVICE: (Circle one)

Army 1 — WAC 5
Navy 2 — WAVE 6
Marines 3 — SPAR 7
Coast Guard 4 — Merchant Marine 8

10. a. Date of entry into Service ..... Rank .....

b. Length of Service ..... years ..... months, rank at discharge .....

11. EDUCATION IN SERVICE:

a. Did you take any ASTP, Navy V or other technical courses during Service?
Yes 1 No 2
(Circle one and only one of these two code numbers)

b. If yes, list, give approximate time in attendance, official designation of course and institution.

12. NATURE OF MILITARY SERVICE: Summarize all assignments with approximate dates, indicating whether or not your professional training and experience were utilized to any extent. If not well utilized, give reasons.

13. COMMENTS ON YOUR MILITARY SERVICE WITH REFERENCE TO:

a. Effectiveness of your geological work in World War II.
b. Suggestions for better utilization of geologists in national emergency.

FIG. 1 (Continued)

A five-point rating scale (Table XI) was devised and applied objectively to all replies concerning utilization in military assignment. Initial analysis was made by the writer, and his findings were checked by a committee from the U.S.G.S. The opinions expressed by many respondents (a great many gave no usable opinions) were then summarized according to a pattern which is being applied to all societies participating in the survey (Table XV).

In addition to the data secured from the questionnaires, mention should be made of the excellent reports of the war service committee of the Association, and other published reports and articles to which the writer has had access. The cooperation of the societies, of the U.S.G.S., and of the many individuals who gave of their time is deeply appreciated by the Department of the Army and the writer.[3]

The figures in Table I are totals. Individual tables given hereafter differ somewhat from these totals because all respondents did not answer all questions. The percentage of geologists in uniform (19.5 per cent) is determined on the basis of the total respondents, not the total mailing list.

TABLE I

NUMBERS INCLUDED IN SURVEY

	Questionnaires Mailed	*Questionnaires Returned*	*Reported Military Service*	*Percentage of Respondents in Armed Services*
A.A.P.G.	5,300	2,355	527	22.4
G.S.A.	1,800	787	87	11.1
	7,100	3,142	614*	19.5

* It is not known what percentage of all geologists in uniform is represented by this figure. The American Association of Petroleum Geologists has reported that 746 of its members experienced active military service; approximately 70 per cent of these responded to the survey.

Because of the preponderance of respondents who were members of the A.A.P.G., in ratio of approximately 3 to 1, Table II reflects a similar preponderance of geologists employed by industry. In fact, the industry, academic, and Government or State categories include more than 95 per cent of the respondents. One factor to be noted is the very small number reporting that they are currently in the military service. This suggests a general exodus of geologists from military service at the end of the war. Although the data are not available for all other fields, it is believed that the current circularization for the new edition of *American Men of Science* will indicate a much larger number of engineers and scientists in other fields who have undertaken a military career.

No particular comment need be made concerning Table III which describes the distribution of formal education in geology among members of the two so-

[3] Special thanks are due to Frank Whitmore, Donald Dow, and Harold Hawkins of the Military Geology Unit, U.S.G.S., for assistance in analyzing questionnaires; to W. W. Pangborn, librarian of the Military Geology Unit for assistance in searching the literature; and to Don L. Carroll and W. W. Rubey for critical reading of the manuscript.

TABLE II

PRESENT WORK OF GEOLOGISTS

Work	*Number*	*Percentage of Total*
Industry (economic geology)	2,016	67.4
Academic	492	16.5
Government or State agency	348	11.6
Military service	12	.4
Student	47	1.6
Retired, unemployed, and miscellaneous (Probably includes some consultants)	74	2.5
Total	2,989	100.0

cieties. This is based, of course, on an incomplete list of 2,949. It is worthy of note that the number without a formal degree totals only 5.3 per cent. Table IV compares the distribution of formal education in geology with that in chemistry and physics, although the sample from geology is smaller. It is also noteworthy that the results from geology are almost identical with those in chemistry but that a considerably larger percentage of respondents from the Institute of Physics indicates that they received no formal degree in physics. Discussions with mem-

TABLE III

FORMAL EDUCATION OF GEOLOGISTS

Highest Degree in Geology	*Number*	*Percentage of Total*
Doctorate	821	27.9
Master	669	22.7
B.A. and B.S.	1,303	44.1
Incomplete college training	120	4.1
No college training	36	1.2
Total	2,949	100.0

bers of the Institute indicate that this is not a reflection of lack of formal training but of the fact that their circularization included all subscribers to the journal published by the Institute.

TABLE IV

COMPARISON OF FORMAL EDUCATION IN FIELD OF SPECIALIZATION OF GEOLOGISTS, CHEMISTS, AND PHYSICISTS

Scientific Field	*Total Number of Cases*	*Educational Level (Percentage of Total)*			
		Ph.D.	*M.A. or M.S.*	*B.A. or B.S.*	*No Degree*
Geology	2,949	27.8	22.7	44.1	5.3
Chemistry	30,405	28.9	19.5	45.2	6.4
Physics	6,284	36.3	19.7	19.4	24.6

TABLE V

EDUCATIONAL LEVEL OF GEOLOGISTS PRESENTLY ENGAGED IN VARIOUS KINDS OF WORK

Present Work	*Educational Level*						*Total Number*
	Ph.D.	*M.A. or M.S.*	*Graduate Training No Degree*	*B.A. or B.S.*	*Incomplete College*	*No College*	
Industry	252	482	376	737	91	23	1,961
Academic	381	47	28	9	12	9	486
State or Government agency	154	101	38	37	8	3	341
Military service	1	2	6	5	0	0	14
Student	0	20	18	5	4	0	47
Retired, unemployed, misc.	33	17	4	20	5	1	80
Total	821	669	470	813	120	36	2,926

Analysis of the formal education of geologists in terms of their present work indicates an interesting relationship of which most geologists are aware: that a very large number enter industrial employment without benefit of training at the graduate level. In Table V an additional column has been added representing some graduate training without the granting of a formal advanced degree. This indicates that of the respondents who reported the baccalaureate as their highest degree, approximately one-third have completed a significant amount of graduate work. As would be expected, the percentage of Ph.D. degrees in academic work is very high, and this category is also the largest in the line representing employment by State or Government agencies. By contrast, the number of Master degrees in academic work is relatively small in comparison with those in industry and in State or Government work.

Tables II and VI are compared in Table VII which follows. It is assumed that the ratios of the present employment of geologists among the various work categories shown in Table II are a fairly accurate reflection of the ratios of pre-

TABLE VI

PRINCIPAL WAR WORK OF GEOLOGISTS

	Number	*Percentage of Total*
Industry	1,579	52.8
Academic	329	10.8
Government and State agency	488	16.3
Military service	536	18.2
Student	41	01.3
Retired, unemployed, and miscellaneous (probably includes consultants)	21	00.6
Total	2,994	100.0

war employment in the same categories. Based on this assumption, the figures in Table VI indicate that the industrial and academic employment of geologists during the war dropped very appreciably, with a considerable shift to employment by Government or State agencies, and to the military service. Unfortunately, because all questionnaires were not completely filled out, the figures in these tables do not approach the totals reported in some others, but the trend is certainly clear, and to a very considerable degree is the same one illustrated by data from other fields of science and engineering.

TABLE VII

PRESENT WORK STATUS OF GEOLOGISTS DISTRIBUTED ON BASIS OF THEIR PRINCIPAL WAR WORK

Kind of Principal War Work	*Total*		*Present Work of Geologists*											
			Academic		*Economic Geology*		*Student*		*Government or State Agency*		*Military Service*		*Retired or Unemployed*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Academic	324	10.8	275	55.9	19	0.9	1	2.1	16	4.6	0	0.0	13	17.5
Economic geology	1,579	52.9	50	10.2	1,492	74.0	7	14.9	11	3.2	0	0.0	19	25.7
Student	41	1.4	6	1.2	22	1.1	11	23.4	2	0.6	0	0.0	0	0.0
Government or State agency	488	16.3	97	19.7	94	4.7	3	6.4	275	79.0	0	0.0	19	25.7
Military service	536	17.9	60	12.2	387	19.2	25	53.2	44	12.6	12	100.0	8	10.8
Retired or unemployed	21	0.7	4	0.8	2	0.1	0	0.0	0	0.0	0	0.0	15	20.3
Total	2,989	100.0	492	100.0	2,016	100.0	47	100.0	348	100.0	12	100.0	74	100.0

TABLE VIII

PRINCIPAL WAR WORK OF GEOLOGISTS WITH DIFFERING DEGREES OF ACADEMIC TRAINING

Educational Level	*Total*		*Principal War Work*											
			Academic		*Government State or Agency*		*Industry*		*Student*		*Military Service*		*Retired or Unemployed*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Ph.D.	818	27.3	235	74.4	243	49.4	237	15.2	2	4.7	87	15.7	14	58.4
Master	680	22.8	30	9.5	122	24.8	389	24.9	11	25.6	125	22.5	3	12.5
Incomplete graduate training	475	15.9	19	6.0	50	10.2	273	17.5	12	27.9	118	21.3	3	12.5
Bachelor	854	28.5	14	4.4	58	11.8	558	35.6	15	34.9	207	37.3	2	8.3
Incomplete college training	129	4.3	12	3.8	15	3.0	84	5.4	2	4.6	14	2.5	2	8.3
No college training	37	1.2	6	1.9	4	0.8	22	1.4	1	2.3	4	0.7	0	0.0
Total	2,993	100.0	316	100.0	492	100.0	1,563	100.0	43	100.0	555	100.0	24	100.0

Table VIII shows the reported relationship between the principal work of geologists during the war and their formal training in geology. For the 3,003 geologists reporting there seems to be little percentage difference in their shift of principal work by comparison with Table III, which indicates the distribution of formal training. Entrance into the Armed Services by geologists who held the Bachelor or Master degree is proportionately larger, approximately twice

that of those holding the doctorate. This may be partly the result of the nature of employment of those with Ph.D. degrees, but the determining factor probably was the age of individuals involved. Again the transfer of activity from peace-time academic and industrial activities to war-time civilian agencies and military service is marked.

TABLE IX

DISTRIBUTION OF RANK OF GEOLOGISTS IN ARMED SERVICES*

	Totals by Service	*Enlisted*	*Company Grade*	*Field Grade*	*General Officer*
Army	227†	49	83	94	1
Air force	176	30	90	56	0
Navy	191	12	142	37	0
Marines	5	2	2	1	0
Coast guard	3	0	3	0	0
Totals by rank	602	93	320	188	1

* Rank held at discharge from Armed Forces.
† Read across for totals in first column.

Table IX indicates not only the distribution of rank among geologists in the Armed Forces, but also shows the distribution in the various Services of those who responded to the circularization. It is noteworthy that approximately 85 per cent held commissions, although many entered the Services as enlisted men. The details are not given in the table because field grade ranks are summarized, but detailed analysis revealed that 8 respondents attained the rank of colonel in the Army; 2 in the Air Force; none who reported had reached the comparable grade of captain in the Navy. The single brigadier general was a special case of direct commissioning of a distinguished geologist who held the rank for approximately 6 months.

Table IX agrees very well with the previous survey of 149 geologists in uniform made by the national service committee of the A.A.P.G. which reported 34 per cent of field grade, 56 per cent of company grade and 10 per cent in the enlisted ranks.

The very high percentage of geologists who held commissions is certainly indicative of the high general ability of the individuals concerned and their adaptability to the new demands of a military career.

TABLE X

METHOD OF ENTRY INTO ARMED SERVICES

	Number	*Percentage of Total*
Direct commission	201	34.3
Reserve commission	136	23.2
Voluntary enlistment	150	25.6
Draft	99	16.9
Total	586	100.0

Of the 586 respondents who reported their method of entering the Services, a surprisingly large percentage were inducted through direct commissions. The smallest percentage was drafted. The effect on these figures of voluntary enlistments prior to imminent draft induction is not known.

Reference to other fields indicate that the percentage of reserve officers among geologists is comparable with those in such fields as physics and chemistry but was considerably greater proportionately than in psychology and geography where entrance through the Reserve Corps was recorded as being approximately 8 per cent of the total respondents. Other factors being equal, one would suspect that if almost one-fourth of the geologists who entered military service did so *via* the reserve, the Services must have recognized, prior to the war, the value of geological work and the role which geologists might play in a national emergency. Unfortunately the utilization of geologists, as compared with the method of entrance into the Services (Table XII), shows that this was not the case. A very high percentage of the geologists who entered through the reserve performed little or no technical work while in Service. This may be due to the circumstance that many of the members of the A.A.P.G. are graduates of land-grant colleges and universities where R.O.T.C. training is required. Their reserve commissions were in the branch of service represented by the Reserve Officers' Training Corps at the institution, and no transfer was accomplished to another basic branch in order to provide a mobilization assignment more fitting to the individual officer's civilian training and experience. The Services are now examining this situation and it is anticipated that procedures will be established to modify this situation.

TABLE XI

TECHNICAL UTILIZATION OF GEOLOGISTS WHILE IN UNIFORM

Utilization Categories	*Number*	*Percentage*	*Definitions*
1	30	5.0	Well utilized as geologist at level of technical competence
2	131	21.6	Utilized geological skills for at least half of time in armed forces
3	141	23.3	Utilized in technical field collateral with geology during most of service
4	84	13.9	Utilized as geologist or in related technical field during only short part of service
5	219	36.2	Not used as geologists or in related technical field during service
Total	605	100.0	

Table XI indicates the use of the training and experience of the 605 geologists in uniform who reported on this subject. The criteria used to establish the utilization scale are listed at the right. By definition, only those men were included in utilization category No. 1 who worked in uniform as geologists and applied their training or experience directly. Those who engaged in photographic interpretation and similar activities were placed in Group 2 with others who used their geological skills during only a part of their military service. Group 3 included those who performed any technical duties which utilized their general

background or scientific training, for example, meteorology or radar. Groups 4 and 5 are self-explanatory.

This table reveals that 50 per cent of the geologists in uniform, on the basis of their military assignments and their own opinions, performed technical duties utilizing their training or experience during little or none of their time in uniform. A number of individuals in Category 5 pointed out, however, that their experience in field work was extremely useful to them in combat operations.

Comparison of Table XI with the report of the national service committee reveals some difference in utilization, perhaps because of the smaller number of

TABLE XII

METHOD OF ENTRY OF GEOLOGISTS INTO ARMED SERVICES IN TERMS OF DEGREE OF UTILIZATION OF THEIR PROFESSIONAL AND TECHNICAL ABILITIES

Degree of Utilization	*Total*		*Method of Entry*							
			Draft		*Voluntary Enlistment*		*Reserve*		*Direct Commission*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
1	31	5.3	1	1.0	3	2.0	4	2.9	23	11.4
2	111	19.0	18	18.2	26	17.3	8	5.9	59	29.4
3	141	24.1	23	23.2	37	24.7	21	15.4	60	29.9
4	84	14.3	20	20.7	16	10.7	24	17.7	24	11.9
5	219	37.3	37	37.4	68	45.3	79	58.1	35	17.4
Total	586	100.0	99	100.0	150	100.0	136	100.0	201	100.0

TABLE XIII

COMPARISON OF TECHNICAL USE OF GEOLOGISTS, CHEMISTS, PHYSICISTS, AND PSYCHOLOGISTS, WHO SERVED IN ARMED FORCES

Scientific Field	*Total Cases*	*Degree of Utilization and Percentage*				
		1	*2*	*3*	*4*	*5*
Geologists	605	5.0	21.6	22.3	13.9	36.2
Chemists	4,043	24.0	12.6	20.3	15.8	27.3
Physicists	606	53.3	15.8	2.4	23.0	5.5
Psychologists	1,168	45.6	26.5	14.0	8.7	5.2

individuals involved. Of 149 geologists, 65 (44 per cent) reported direct use of geological experience, 33 (23 per cent) reported slight or indirect use, and 49 (33 per cent) reported no use of their technical background.

Chemistry and physics were selected for comparison with geology because physics has been highly publicized as absolutely essential to the war effort and

in numbers (both total numbers and service in the Armed Forces) was comparable with geology. In terms of relative education and industrial application, chemists are similar to geologists. Both chemistry and physics are familiar to the Armed Services and have been utilized extensively by them in research and development programs for many years. Chemistry is also used extensively in combat; physics came to be so used during the war just ended. Geology, on the other hand, has been relatively unfamiliar to the Services. This was certainly brought out by the record which shows that the utilization of geologists in the first category is very poor indeed. On the other hand, even in chemistry, more than 40 per cent of the respondents are included in categories 4 and 5 involving little or no technical use of their experience and training.

Among the psychologists whose importance suddenly loomed large because of the necessity for the testing and classification of millions of men, 86 per cent of the more than 1,100 psychologists who responded to the questionnaires fell into categories 1, 2, and 3. This is by contrast with physicists who included approximately 72 per cent in these categories, chemists 57 per cent, and geologists 50 per cent.

In addition to the opinion by the Armed Services that physics and psychology had become key fields as concerned their applications to military activities, one other circumstance accounts for the better utilization of uniformed personnel representing these disciplines. Owing to the work of key physicists on the National Roster and the National Research Council, transfers from less technical to more technical positions were obtained for approximately 25 per cent of the physicists reporting for duty in the Armed Services. In the case of psychologists, a reporting system was set up and the same procedures were carried out, resulting in the transfer and also in the better classiffication of psychologists who entered the Service. A very high percentage of the latter entered through direct commission.

TABLE XIV

UTILIZATION OF GEOLOGISTS IN TERMS OF FORMAL EDUCATION

	Total	*Ph.D.*	*M.A. or M.S.*	*B.A. or B.S.*	*No Degree*
Used as geologist	29	14	6	7	2
Used in related technical skills	246	39	56	147	4
Little or no technical usage	301	34	75	180	12
Total	576	87	137	334	18

Table XIV summarizes the utilization of geologists in the Armed Services in terms of their formal training in geology. The numbers involved are so few that no definitive conclusions can be drawn from this table. In the case of those possessing the Bachelor or the Master degree, the relative number utilized in the 3 categories is certainly comparable. The fact that a large number of those with the Ph.D degree were well utilized is probably a result of age and direct commission for specific work assignments.

OPINIONS OF GEOLOGISTS IN SERVICE

Reference to the questionnaire (Fig. 1) reveals that questions 12 and 13 ask the respondent for his opinion concerning: (a) his effectiveness as a geologist while serving in the Armed Services; and (b) his concept of action which would improve the effectiveness of geology or geologists in any future international emergency.

Most respondents were content to discuss their personal experiences while in uniform or coupled these with suggestions for application of geological techniques to military problems. A relatively small percentage considered the broader question of future planning. Their opinions are summarized in Tables XV and XV-A. The topical headings used therein result from analysis of several thousand

TABLE XV

UTILIZATION SUGGESTIONS FOR BETTER USE OF GEOLOGISTS

Utilization Suggestion	*Total Number of Opinions*	*Percentage of Geologists Making Suggestion*
Use technical personnel where needed in technical capacity only in either civilian or military agencies dependent on national need	43	26.2
Use technical personnel only as civilians	11	6.7
Use technical personnel as civilian consultants in uniform (technicians, technical representatives, *et cetera*)	13	8.0
Use only within Armed Forces and make provision for transfer within or release from Armed Services when technical abilities are no longer needed	35	22.5
Use technical personnel in Armed Forces in any way that men are needed without reference to their technical qualifications	8	4.8
Provide better classification, assignment, supervision, and personnel management	82	50.0
Total number of opinions	194	
Total number of geologists expressing these opinions	164	

replies to this question. For purposes of the table, the grouping of opinions has been somewhat over-simplified. In general, it reveals the same relative pattern as was produced by respondents from other fields of science or engineering.

Perhaps the most common complaint in regard to personnel assignment practices may be paraphrased as "*classification and assignment personnel were uninformed as to the nature of geology, its applications to military activities, and the technical capabilities of geologists.*" As a result, many respondents mentioned types of utilization which would, in their opinion, apply geological techniques most effectively to the realization of the mission of the Armed Services whether applied by civilians or uniformed personnel. These are summarized in Table

XVI. Of necessity, the topical statements have been over-simplified to include the similar but variably expressed proposals of the respondents.

TABLE XV-A

ORGANIZATION AND PROCEDURE SUGGESTIONS FOR BETTER USE OF GEOLOGISTS

Organization and Procedure Suggestions	*Total Number of Opinions*	*Percentage of Geologists Making These Suggestions*
Use present Selective Service System	0	0.0
Use some new system or agency for selection or use National Service legislation	65	87.8
Commission scientists directly from civilian life	2	2.7
Modify Selective Service System to make it scientifically selective	1	1.4
Pool all scientific and technical personnel and assign wherever needed	12	16.2
Improve the Reserve program	3	4.1
Better national collection of maps	1	1.4
Total number of suggestions	84	
Total number of geologists making these suggestions	74	

TABLE XVI

SUGGESTED APPLICATIONS OF GEOLOGY TO MILITARY ACTIVITIES

Photo-interpretation and terrain intelligence	67
Mapping, charting, and intelligence work	49
Combat intelligence	8
Staff advisors (Corps, Army, and higher)	34
Petroleum exploration and rehabilitation of oil fields in conquered territory	25
Exploration for new mineral resources	21
Use of resources by Military Government, or in economic warfare	9
Location of construction sites and advice on heavy construction (air fields, gun replacements, *et cetera*)	21
Ground water and drainage	18
Analysis of beaches and planning of landings	9

In addition to the major categories of opinion summarized in Table XVI, individual or small numbers of respondents suggested: "use older geologists as instructors in service schools," "use younger geologists for combat duties," 'use for geological duty with operating units," *et cetera.*

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS RESULTING FROM SURVEY

SUMMARY

1. From a total of approximately 7,100 questionnaires distributed to geologists, 3,142 responded. Of these, 614 reported some service in the Armed Services during World War II.

2. Of the total reporting, two-thirds are presently employed in industry; during the war slightly more than half were so employed.

3. Of those reporting military service, the distribution between the three major services was fairly even; 85 per cent held officers rank.

4. As for method of entry into the Service, approximately twice as many entered *via* direct commissions as were drafted.

5. In regard to utilization, only 5 per cent reported direct and complete use of their competence as geologists. Many indicated indirect use of geologic experience in combat, although no direct technical use was made. The most common alternative technical utilizations were in photo-interpretation, intelligence, and meteorology.

6. A large proportion felt that the Armed Services were relatively unaware of the potential role of geologic techniques and geologists in military activities, and that their activities suffered as a result.

CONCLUSIONS DRAWN FROM SURVEY[4]

1. It may be concluded that during World War II, almost all civilian geologists were engaged in work bearing directly or indirectly on the program of the conflict. Those in industry were engaged in exploration for, or exploitation of, natural resources to support the war effort. Those remaining in the academic environment spent much of their time, almost without exception, training students in uniform for the various Armed Services educational programs. Many more were engaged in the strategic-minerals program of the United States Geological Survey.

As the intensity of the war increased, the need for regulation of the use of our mineral resources increased proportionately. Thus, as regulatory agencies were established by the Government, civilian geologists assumed important parts in the War Production Board, Office of Price Administration, Metals Reserve Company, and others. Geologists of these organizations studied 140 mineral commodities, with especial attention to the use of low-grade supplies. Geologists were also members of the 200-man War Metallurgy Committee of the National Research Council, which attacked hundreds of problems concerning the use and processing of ores. The knowledge of American economic geologists concerning foreign mineral resources was put to good use by the Board of Economic Warfare, the Foreign Economic Administration, the Army-Navy Munitions Board, and by the Intelligence Branch of the United States Army Air Forces; the latter also used geologists to assist in outlining bombing targets. Geologists, and especially mineralogists, took part in the research projects of the Office of Scientific Research and Development and the Signal Corps.

As the war progressed, civilian geologists also contributed more and more to terrain intelligence. Geologists both in uniform and out were members of the

[4] The writer is indebted to Frank Whitmore of the United States Geological Survey for much of the information in Section 1.

Office of Strategic Services, assigned to preparation of strategic reports, maps, and topographic models in Washington, and to various confidential missions abroad in geology and allied fields such as collection of maps and collation of captured intelligence documents.

The largest geological group engaged in terrain intelligence work was the Military Geology Unit of the United States Geological Survey, Department of the Interior; formally organized in June, 1942, this Unit is still functioning. During the war, it employed 88 geologists, 26 other specialists, and 43 sub-professionals. Using as source material geologic literature and maps, topographic maps, and aerial photographs, the Unit prepared folios of maps and brief texts setting forth the facts of passability of terrain, possible air-field sites, location of construction materials and drinkable water, and other information concerning enemy-occupied foreign areas which would be of use in operational planning. Beginning in May, 1944, geologists from this Unit were assigned to the Office of the Engineer at GHQ and the Army and Corps headquarters in both the Pacific and European theatres, where they prepared intelligence reports more detailed than those originating in Washington. They also served as consultants, especially for engineer troops, on specific problems to which a knowledge of geology could often bring a solution.

In the occupational phases of the Japanese war, geologists of the Military Geology Unit contributed by surveying the mineral resources of Japan and making the information available in a series of reports which have been widely used both by occupation authorities and by the Reparations Mission to Japan. Civilian geologists employed by the War Department participated in this type of work, both in the Pacific and Europe, and continue to administer large sections of the mineral industry in occupied countries.

2. The record also indicates that geologists in uniform adapted themselves readily to their military duties and made an important contribution to the active phases of the war. The high percentage of officers among the geologists who reported active service corroborates this conclusion. There is no way to measure quantitatively whether they would have been more valuable to the Services had their technical experience been utilized more effectively, but the trend of the evidence suggests this in many individual cases.

3. It is obvious that during the early years of the war, there was no widespread awareness among the Armed Services of the potential uses of geology and geologists, either in or out of uniform. This situation has improved somewhat, but still leaves much to be desired.

It was, in part, this lack of acquaintanceship with the applications of geology which led to rather widespread mis-assignment of geologists in the Services. The statistics (Table XI) indicate that approximately half of all geologists in uniform performed essentially no duties directly involving their technical experience or training.[5] When one considers the small number of geologists in the Services

[5] "Report of Sub-Committee to Assemble and Study Service Records of Members Returned from

it seems obvious that a considerable number of military positions which needed a background of geologic information and experience were manned by men technically unfitted to perform their duties with effectiveness. It is also evident that the Services spent time and money training inexperienced personnel in the techniques of photo-interpretation and terrain intelligence when they might have utilized the services of geologists, otherwise unused technically, for these important tasks.

4. The situation described in the foregoing paragraph sprang largely from two circumstances: (a) the failure to profit from the lessons of World War I and the effective example of the German armies in both wars;[6] and (b) the essential absence of cooperation and working liaison between the Services and the geological profession during the period from World War I to World War II.

In time of crisis, the Armed Services must depend on proved instrumentalities and methods of warfare. They usually can not afford to experiment with new ideas. Furthermore, the constant rotation of personnel at all times, the abrupt multiplication of numbers during mobilization, and the necessity for immediate action when war comes, prevent experienced and thorough analysis of new tools or procedures. One can not expect the Services to grasp at new techniques suggested by civilians, or even proffered by a few uniformed personnel, if they are proposed during a time of crisis. The critical time for reorganization, or for the inclusion of new techniques in such a way as to become S.O.P.,[7] is during the years of peace. Only in this way will they be used effectively in emergency. And only by the maintenance of a close relationship between Science and the Services can scientific techniques become an integral part of military doctrine.

5. The Reserve Program, in dealing with professional geologists, was ineffective.

It has been the custom between wars to reduce the Armed Forces to a very small planning organization. The reservoir for replenishment and expansion is the Organized Reserve. Represented within the Reserve are all walks of life, and many skills which could be applied to the problems of national defense during periods of peace if there were an *appropriate mechanism* for their discovery and use. Unfortunately, this mechanism did not generally exist for the reserve scientist before World War II. As a result, more than one-third of the professional scientists and engineers of whom we have record were technically unused in the Services. It can be reported that the Department of the Army has recognized this problem and has established a reserve program designed particularly for scientists and engineers.[8]

Service," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 5 (May, 1947), pp. 887–93. "The fact that geologists were engaged in such a great diversity of military assignments is itself indicative of a lack of the sort of personnel management which should place highly trained technical men in the positions for which they are eminently qualified and urgently needed" (p. 889).

[6] A. H. Brooks, "The Use of Geology on the Western Front," *U. S. Geol. Survey Prof. Paper 128-D* (1920), pp. 85–124.

[7] S.O.P.: Standard Operating Procedure.

[8] *Department of the Army Cir. 127*, Sec. V (May 5, 1948).

6. On a national scale, our Selective Service law and social pressures were unrealistic as applied to the scientist. We can not again afford to drive technical manpower into uniform willy-nilly in order to fill local draft board quotas. Nor can we afford to lose the many scientific man-years which were expended by research project administrators during World War II to keep civilian technical organizations intact so that they could effectively perform their allotted war mission. This is a matter of concern to all citizens, but particularly to all scientists. The most effective means of satisfying the needs of urgent military and civilian scientific activities during war, is by means of national pooling and allocation of our national technical manpower resources.

RECOMMENDATIONS

At the risk of being repetitive, reference is again made to the excellent report of the A.A.P.G. national service committee. Its recommendation that "geologists should, to the maximum extent deemed desirable by the War and Navy departments, be included in the organizational structure of the military services as officers, enlisted personnel, and/or civilians"[9] was very properly approved by the executive committee of the Association. An additional recommendation, not approved by the executive committee, proposed that "problems relating to military geology be made one of the designated responsibilities of the standing committee on applications of geology . . . to study, report upon, and make recommendations respecting the utilization of geologists by the military services."[10]

The assignments suggested for geologists within the Armed Services have been discussed in a previous section of this paper. The *general* recommendations submitted by the national service committee may be paraphrased as: (1) improve the Armed Service personnel policies and practices; (2) encourage utilization of geological techniques and geologists by the Services; (3) inform geologists of appropriate Service assignments which could utilize their technical training and experience; (4) use the capabilities of reserve officers during peacetime for the solution of technical problems; (5) maintain the Military Geology Unit of the United States Geological Survey and employ it for the training of reserve officers.[11]

Bearing in mind the work of this committee, the writings and orally expressed opinions of many geologists with whom the writer has discussed this problem, and the results of the survey herein described, the following recommendations are proposed.

1. *A complete analysis of the role played by geologists and geology in the late conflict be sponsored and financed cooperatively by the geological societies.*—The information required for an historical analysis of this type will soon be unavailable. Such a study would be invaluable in terms of producing a better realization of the importance of geology in both peace and war. It is believed that it would require the fulltime services of a competent geologist for the better part of a year.

[9] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 5 (May, 1947), p. 885.

[10] *Ibid.*

[11] *Bull. Amer. Assoc. Petrol. Geol., ibid.*, p. 889.

2. *A permanent committee representing organized geology be created at once for official liaison with the Department of the Army on matters of mutual concern.*—The writer can state categorically that the Chief of Research and Development, Army General Staff, and the Director of Personnel and Administration (G–1) would welcome the formation of such a committee. It would provide the needed liaison between organized geology and the Army at a sufficiently high level to make recommendations meaningful in terms of policy decisions. It would be possible for the committee to work closely not only with the Research and Development Group on technical matters, but also with Army agencies concerned with personnel classification and assignment, and with M.O.S.[12] delineation. Furthermore, it could render invaluable service in the implementation of the technical program now being established for reserve officers who are professional scientists or engineers. It is obvious that such a committee should be composed of geologists experienced in Army organization and operation, but also possessing the scientific confidence of their geological colleagues.

3. *The geological societies should lend their support to proposals for modification of the Selective Service Act calculated to equip it to deal adequately with the scientific and engineering manpower of the Nation.*—Effective use of the Nation's technical manpower in event of war can not be predicated on plans prepared by persons without scientific or engineering background. Nor can science and engineering make an optimum contribution to the Nation's defense when constantly subjected to social, political, or draft-board pressures, calculated to make every individual don a uniform because local quotas must be filled. There is, therefore, definite and immediate need for an informed synthesis of the technical requirements of the Nation during any potential emergency; need for a measurement of demand against supply; need for an end to the type of uninformed thinking which holds that no man can perform his necessary wartime duty in civilian clothing. Only the *concerted support* of organized science and engineering can produce this result; only careful planning over the years will insure adequate distribution of technical manpower, always scarce in wartime, to best satisfy the requirements of a Nation engaged in total war.

CONCLUSION

During the past two centuries, we have established a rich civilization on the North American continent. Through our democratic processes, and the accidental occupancy of a continent vastly rich in resources, we enjoy a living standard unmatched by any other Nation. Our productive capacity has enabled us in two major wars to substitute dollars and material for human lives. But, because we are so well endowed, we have not utilized our resources carefully and we have seen how the absence of a consistent national policy has led to rapid gutting of the cream of our natural resources. As a result, some other parts of the world

[12] M. O. S.: Military Occupational Specialty.

may now surpass us in terms of total raw resources. They certainly surpass us in total manpower.

We emerged victorious from the last war because of our production capacity and our engineering know-how; because we possessed a plethora of resources as compared with the enemy. We shall not be in such a favorable position should war come again.

As one observes the international situation $2\frac{1}{2}$ years after V-J day, it is difficult to discern whether we are engaged in a hard peace or a soft war. The way of life to which we adhere as a Nation is under unremitting political attack. Our best chance for survival lies in demonstrating that our democratic form of government really works and in maintaining our Nation at its maximum strength. This imposes a heavy social responsibility upon science and scientists; for science and the results of scientific labors have become basically important to modern existence.

The geologist stands at the foundation of one important aspect of national strength. As a matter of course, he finds the materials which form the fabric of our economic and military structure. But this is not enough. His is also the responsibility to estimate constantly into the future the potential strength of these resources; to delineate trends; and to inform the Nation of them. The writer conceives this to be as true in peace as in war; to be true for any national resource, whether it be for mineral deposits, for trained manpower to find and exploit them, or for the application of geologic technology to the national defense. Only in this way can the organized geological societies fulfill their necessary contribution to the maintenance of the democratic society of which they are a part.

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GEOLOGY OF WEST TEPETATE OIL FIELD JEFFERSON DAVIS PARISH, LOUISIANA[1]

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ABSTRACT

The West Tepetate oil field, located in the Louisiana Gulf Coast area, was discovered by the Barnsdall Oil Company and Vincent and Welch in 1944. The presence of the structure was first suggested in 1930 by torsion-balance exploration conducted by Vincent and Welch and was subsequently disclosed by various seismograph surveys during 1941–1944. The producing section lies below the *Heterostegina* zone in the middle Miocene, and consists of twelve oil- and gas-bearing sands ranging from 7,600 to 9,900 feet in depth. The structure is a gentle, irregularly elongate dome, believed to have been produced by the deep-seated intrusion of salt, though none has been encountered to date. There is nearly 100 feet of effective closure at the producing levels. Only one fault has been encountered in drilling, though a major regional fault, downthrown on the south, is indicated by seismograph on the north side of the field, probably being a westward extension of the similarly bounding fault in the Tepetate field. The productive limits thus far established enclose 1,400 acres, offering a reserve of 30–40 million barrels of liquid hydrocarbons, and 60–70 billion cubic feet of gas.

INTRODUCTION

Development of the West Tepetate field has shown it to be an oil and gas reserve of major importance. Its discovery was recent, and drilling sufficiently dense, to provide plentiful data for the preparation of a geological report both complete and accurate within the natural limitations of subsurface geological study.

This field has reached that stage in development in which the discovery of new sands has halted. The productive limits of each sand are reasonably well defined, and the structural configuration and location of faults are determined with fair accuracy. Though drilling is continuing and may disclose some variations, it is felt that they will be minor.

The writers were present during the drilling and coring of most of the wells in this field, thus having first-hand knowledge of most phases of its development.

LOCATION AND PHYSIOGRAPHY

The West Tepetate field is in extreme northeastern Jefferson Davis Parish, 40 miles northeast of the town of Lake Charles and an equal distance northwest of Lafayette. Its productive area is largely in Sec. 31, T. 7 S., R. 2 W., and Secs. 25, 35, 36, and 38, T. 7 S., R. 3 W. It is in an area of prolifically productive deep-seated salt-dome structures, the areal distribution and geographic relationship of which are shown in Figure 1. It is just east of the South Elton field and west of the Tepetate field, to both of which it appears to be closely related structurally.

[1] Read before the mid-year meeting of the Association at Biloxi, Mississippi, October 25, 1946. Manuscript received, April 7, 1948.

[2] Consulting geologist. The writers wish to express their appreciation to Barnsdall Oil Company and to Vincent and Welch for their permission to publish this report and for making available a large amount of information essential to its preparation. Thanks are due to R. A. Irwin for the use of data from his wells on the west flank.

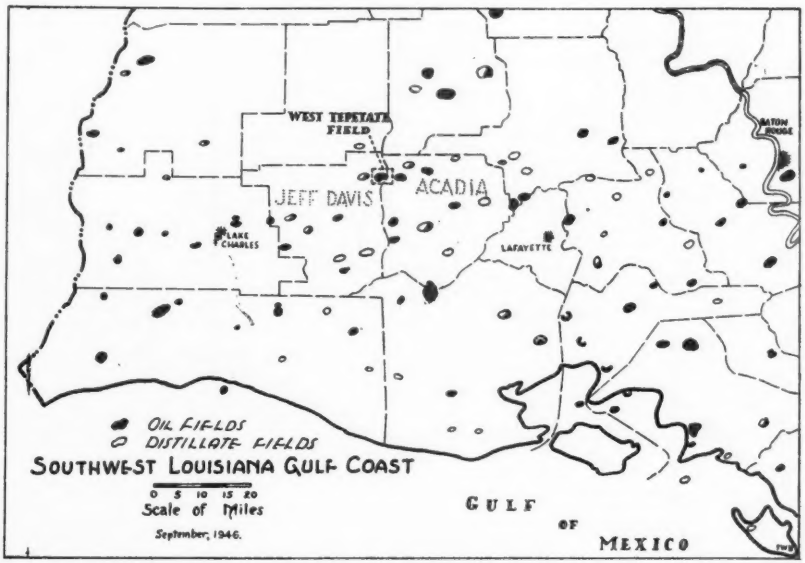


FIG. 1.—Regional sketch map.

Bayou Nezpique' flows south across the east edge of the field, producing, together with its tributaries, a dissected terrane with 25 feet of relief. The surface is partly under rice cultivation, partly in timber, with oak and pine predominating. Surface formations are Pleistocene or Recent, consisting of reddish brown to yellow clays and sandy clays. No surface expression has been noted indicating the presence of structure underlying this area. Difficulty of access, particularly in the timbered swamp area bordering Bayou Nezpique', played a major part in delaying discovery and development. A north-south highway just west of the limits of the field, is the only means of access. Oil outlet is by the Continental Oil Company pipeline to tidewater at Lake Charles.

GEOPHYSICAL HISTORY

Because of its location on a favorable geologic trend, this prospect was partly explored by various geophysical methods many times prior to the actual discovery of production. Its complete delineation and drilling were retarded by the difficult swampy terrane, and by the barrier of unbridged Bayou Nezpique'.

The first indication of subsurface anomaly was apparently recorded in 1930 during torsion-balance exploration by Vincent and Welch which resulted in the discovery of the adjacent Tepetate field. Reflection-seismograph work by various other major oil companies apparently showed local structural anomaly, as leases were taken on the area presently productive, but were dropped without drilling.

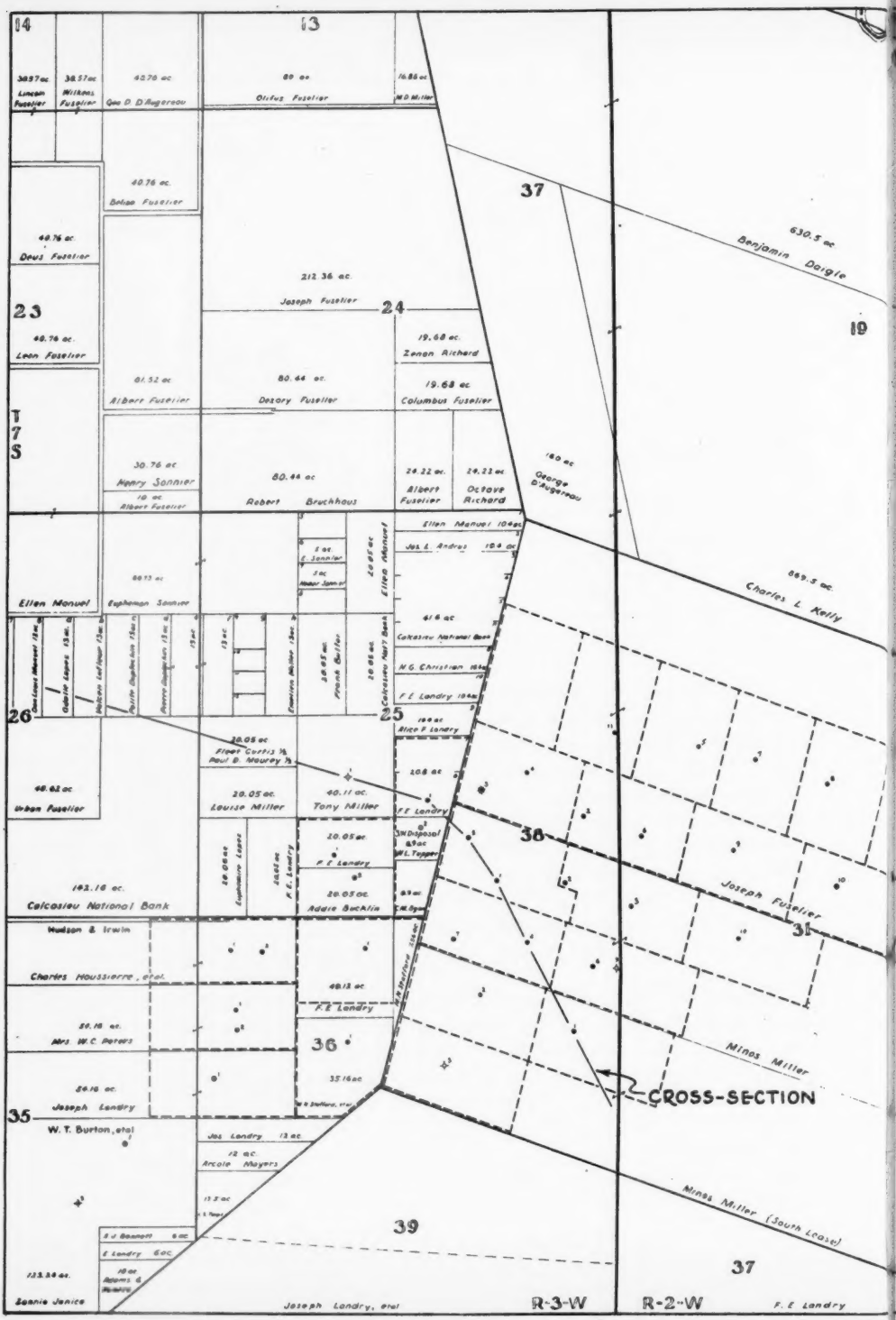
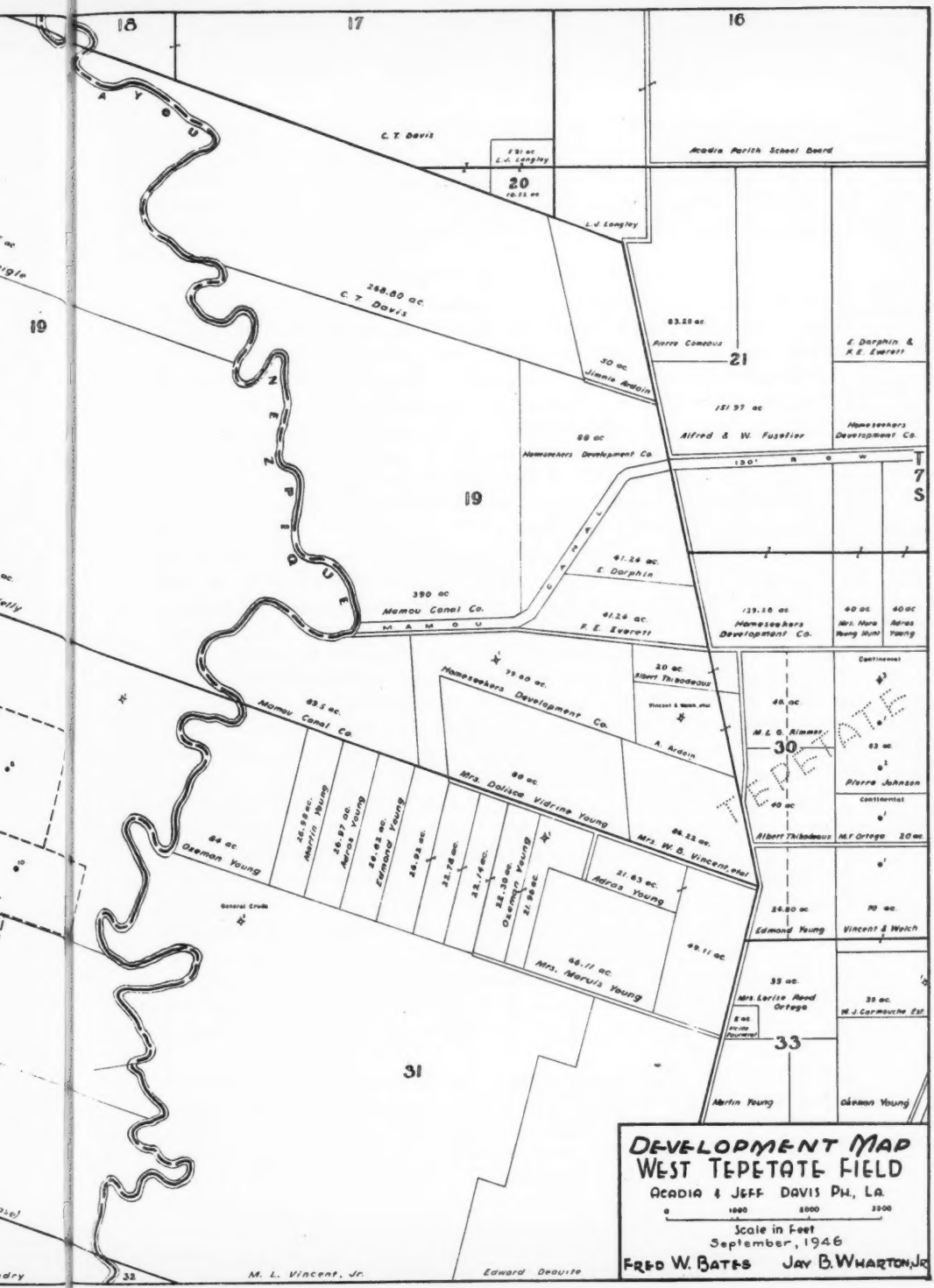


FIG. 2.—Development map



nt map of West Tepetate field.

Reflection-seismograph work by Vincent and Welch in 1941 led to their drilling east of the field, Ardoin No. 1, which blew out and was abandoned. More detailed seismograph exploration was conducted by this operator jointly with the Barnsdall Oil Company between 1941 and 1944, the accuracy and completeness of which eliminated the drilling of many dry holes during development.

DISCOVERY AND DEVELOPMENT

The Barnsdall Oil Company and Vincent and Welch jointly drilled Joe Fusilier No. 1 in Section 31, on the northeast edge of the West Tepetate field. This well blew out from the total depth of 9,580 feet and was abandoned in March, 1944. The first producer was the same operators' Minos Miller No. 1, completed in October, 1944, as an oil well through perforations from 8,516 feet to 8,526 feet in the Klumpp "A" sand, after drilling to the total depth of 10,032 feet.

The initial potential, typical of other wells in this sand, was 405 barrels of 34.8° (A.P.I. corrected) gravity oil on 12/64-inch choke. Tubing pressure was 1,410 pounds per square inch, bottom-hole pressure 3,860 pounds per square inch, and gas-oil ratio 825 cubic feet per barrel.

More than 90 per cent of the field is owned and has been developed jointly by the same operators, with small parts of the southwestern edge of the field drilled by W. T. Burton or R. A. Irwin. Development has been orderly and continuous since discovery, resulting in 27 oil wells (3 dually completed), 1 gas well, and 6 dry holes, exclusive of tests east of Bayou Nezpique'. Drilling is continuing, and most of the new wells are twins to permit production of multiple sands from the same unit. Figure 2 shows the location of wells drilled, development units established, and lease and land-ownerships. The present total daily allowable production is more than 5,000 barrels, and will steadily increase as normal development is completed.

The drilling program has been efficiently handled, with adequate coring, electric logging and deviation surveys made in each hole. Based on the wells drilled, the productive limits include about 1,400 acres. Early attempts were made to complete dually some of the oil wells, which, however, were not entirely successful. Since that time, drilling of twin wells has been substituted to accomplish the purpose of producing from more than one sand under each development unit. The typical casing program is: 100 feet of 16-inch conductor casing, $10\frac{3}{4}$-inch surface casing set at approximately 2,000 feet, and 7 or $5\frac{1}{2}$-inch production casing set through the deepest producible sand. The wells are brought in through 2- or $2\frac{1}{2}$-inch tubing, with the pay section gun-perforated. Ordinarily, no screen is used.

It was early shown by the operators at public hearing before the Minerals Division of the Louisiana Department of Conservation, that one well properly located would drain 40 acres of reservoir. On the basis of this, Conservation Order No. 97 was issued, forming each reservoir of the productive area of West Tepetate into 40-acre units for development, as well as setting up other rules for

drilling and operation. From wells completed at the time, the productive zones were defined as follows: Miller No. 1 zone, those sands between 8,452 and 8,534 feet; Miller No. 2 zone, those sands between 9,162 and 9,200 feet; Miller No. 3 zone, those sands between 8,357 and 8,444 feet. These three zones correspond with the Klumpp "A" sand, the Homeseekers "B" sand, and the lower Ortego-Ortego "B" zone, respectively, as used in Figure 3.

FIGURES

The included electric-log cross section (Fig. 3) is drawn from northwest to southeast across the center of the field, its location being shown on the development map. Its primary purpose is not to show structure or faulting, but rather to give a pictorial presentation of the electrical characteristics of the several sands. Attention is drawn to the persistence of most of the sands and their relationship to each other and to depth. In general, it is self-explanatory. Productive or potentially productive zones are shown in black.

Little need be said of the structure maps. All are drawn on subsea depths to correlative electric-log tops, with dashed contours to show the outer limits of the gas-oil and oil-water contacts. Contours on the isochore, or convergence, maps connect points of equal interval between the two horizons.

STRATIGRAPHY

The customary generalized columnar section of the formations encountered in drilling has not been included. This section is typical of the upper Miocene of the Louisiana Gulf Coast and has been pictured and described several times before. Its similarity and variation from the normal can readily be seen by reference to the electric-log cross section (Fig. 3).

Because of the thorough descriptions already published elsewhere, only the following brief outline is given.

SURFACE. Red and gray shale, coarse sand

RECENT AND PLEISTOCENE: (surface to 1,600 feet) varicolored clays, sand and gravel beds

PLIOCENE. Undifferentiated from lower Pleistocene or upper Miocene

UPPER MIOCENE. Fleming: (1,600–3,000 feet) green shale, medium to coarse sands. *Rangia johnsoni:* (3,000–5,500 feet) interbedded thick sands and shales. *Potamides matsoni*-Catahoula: (5,500–6,850 feet) green and gray shale, thick medium-grained sands, partly calcareous

MIDDLE MIOCENE.[3] Marine Catahoula: (6,850–8,400 feet) predominantly gray shale with a few hard sandy fossiliferous calcareous bodies, several thick coarse sands of the *Marginulina*-Frio section in lower part. Typical occurrence of microfaunal zones: *Discorbis* sps., *Heterostegina texana*, *Bolivinia perca*, *Marginulina idiomorpha*, *Marginulina vaginata*, *Marginulina howei*, *etc.*

LOWER MIOCENE (OLIGOCENE?). Chickasawhay: (8,400–10,000 feet) interbedded shales and few thin broken sands, sand members decreasing in size with depth; top marked by *Cibicides hazzardi*; *Nodosaria blanpiedi* (Hackberry faunal assemblage marker) found at 9,500 feet. No true Vicksburg microfauna encountered to deepest penetration (10,000 feet)

[3] Controversy exists between geologists, whether the *Discorbis*, *Heterostegina*, and *Marginulina* zones should be referred in age to the Miocene or to the Oligocene. With data at hand the question can not be definitely answered, and the writers have accordingly employed the designation in most common use by geologists active in the Louisiana Gulf coastal area. Various authors have in the past presented the evidence for both sides, as ably summarized by H. V. Howe in "Review of the Tertiary Stratigraphy of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (June, 1933).

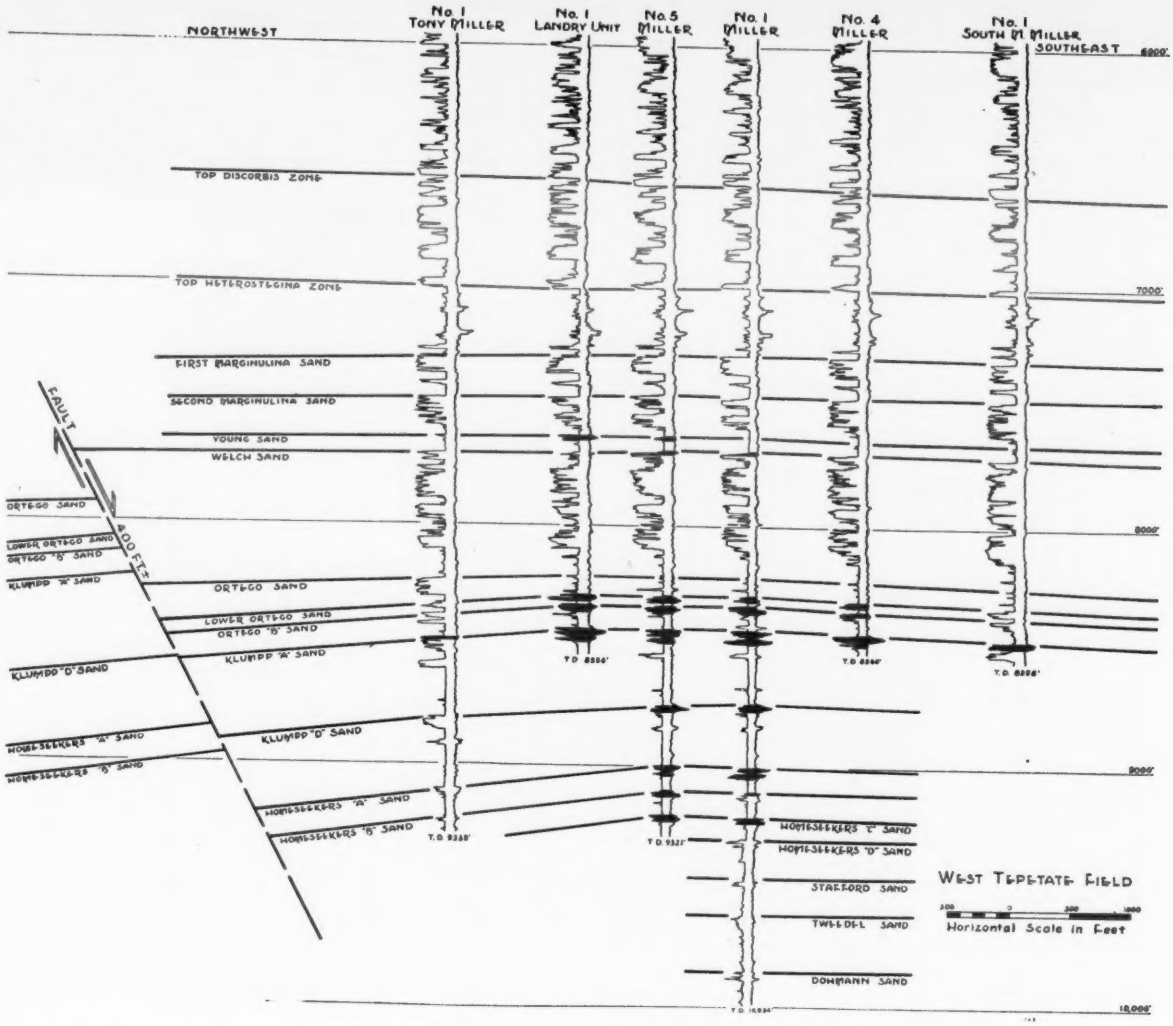


FIG. 3.—Electric-log cross section of West Tepetate field.

FIG. 3.—Electric-log cross section of West Tepetate field.

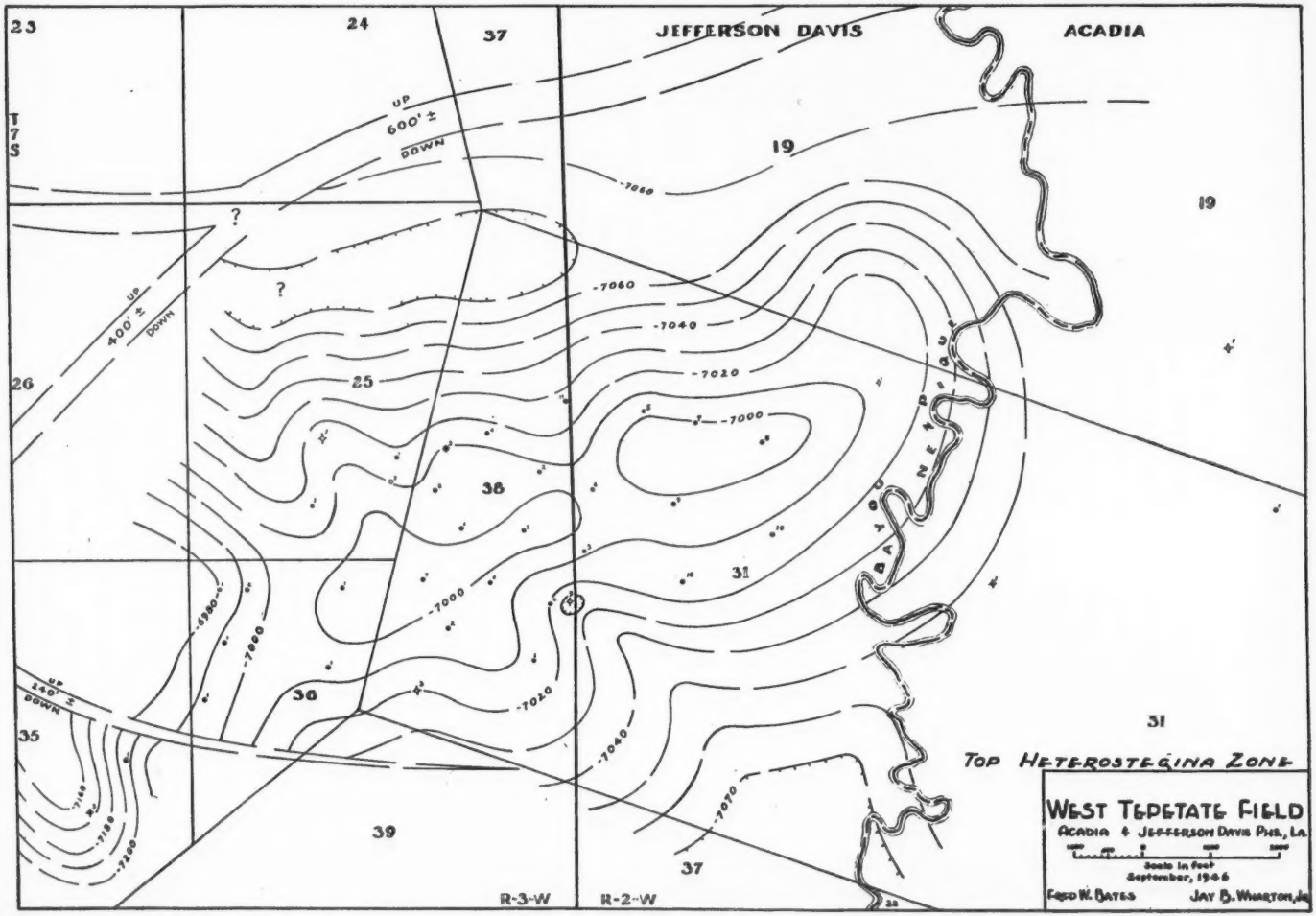


FIG. 4.—Structure contours on top of *Heterostegina* zone.

PRODUCING SANDS

The producing (or potentially productive) sands in the West Tepetate field appear below the Second *Marginulina* sand. All are fairly continuous blanket sands, with normal ranges of porosity and permeability values, broken to varying degrees with shale streaks. The shallowest is the Young sand, encountered at about 7,700 feet. Where present, it is thin and of minor value, reaching a maximum of 15 feet of net effective saturated oil sand. The Welch or Third *Marginulina* sand, 50 feet below the Young, is also poorly developed, and constitutes only a minor oil reservoir. Neither of these sands is now producing.

The Ortego "A" or Fourth *Marginulina* sand, a prolific producing sand at Tepetate and near-by fields, is present on the west flank only, but contains no oil or gas. The other two sands of the Ortego series are well developed and contain major accumulations of gas and oil. The upper of these, the lower Ortego "A," encountered at 8,350 feet, is a blanket sand averaging 15 feet in thickness. In the center of the field it has a gas cap and in two areas the sand is entirely above the gas-oil contact. The deeper Ortego "B" sand is one of the major producing sands of this field. It is a broken sand, with a gas-cap and a maximum net effective saturated oil-sand thickness of more than 25 feet. Eight wells are producing an average of 140 barrels of oil per day each, from this level.

The Klumpp sand series, found between 8,500 and 9,100 feet, is composed of five members, of which two are hydrocarbon reservoirs. The Klumpp "A" is the principal oil-producing sand in the West Tepetate field, whose structure is shown in Figure 5. It has a maximum net sand thickness of more than 35 feet with a small gas cap 15 feet thick on the crest of the structure. Nineteen wells are averaging 200 barrels of oil per day from this sand, per well. The Klumpp "D," encountered at 8,800 feet, has a maximum thickness of more than 30 feet and is a gas-condensate reservoir. No wells now produce from this sand.

The Homeseekers series includes four sands. The first, or Homeseekers "A," has been tested with unsatisfactory results, but will probably produce some oil or gas distillate in certain locations. The Homeseekers "B" (Fig. 6), a broken sand found at about 9,150 feet, has now one well producing 100 barrels daily. The Homeseekers "C" and "D" sands contain producible though minor reserves of gas-distillate, though no wells are yet completed in them.

At 9,500 feet is found the Stafford sand, containing oil in a maximum of 10 feet of net effective sand. The Dohmann sand, the deepest of the possibly productive sands, is encountered at 9,900 feet. It has been tested as containing gas-condensate, but no completions have been made in it.

STRUCTURE

This is a large irregularly ovate gentle uplift with strong northeast- and southwest-trending noses elongating its axis in these directions. It is bounded on the north by a major east-west fault, downthrown on the south, with approximately 600 feet of displacement at the productive levels. Toward the east, this becomes the Maccabees fault which similarly bounds the north flank of the Tepetate field.

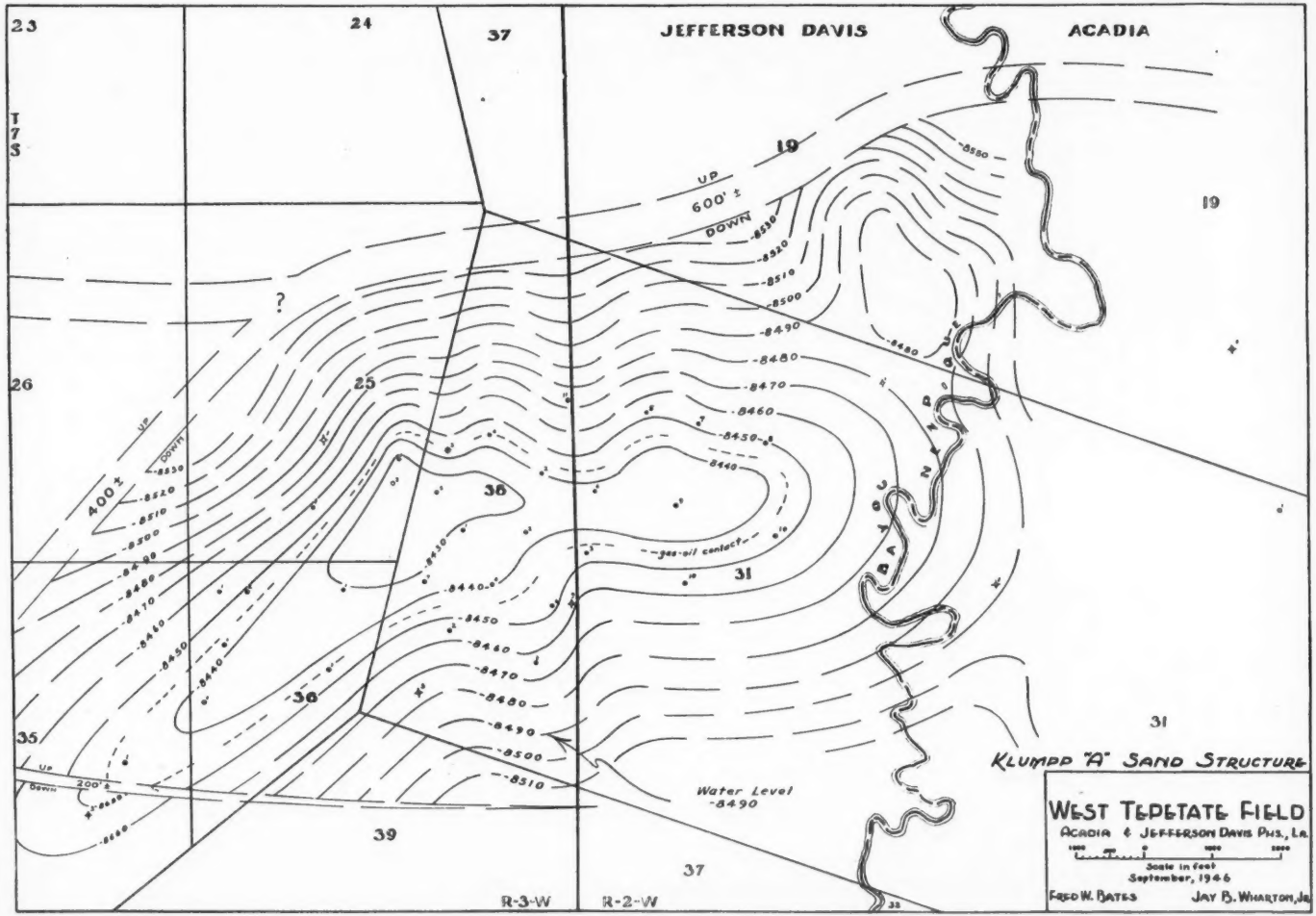


FIG. 5.—Structure contours on top of Klumpp "A" oil sand.

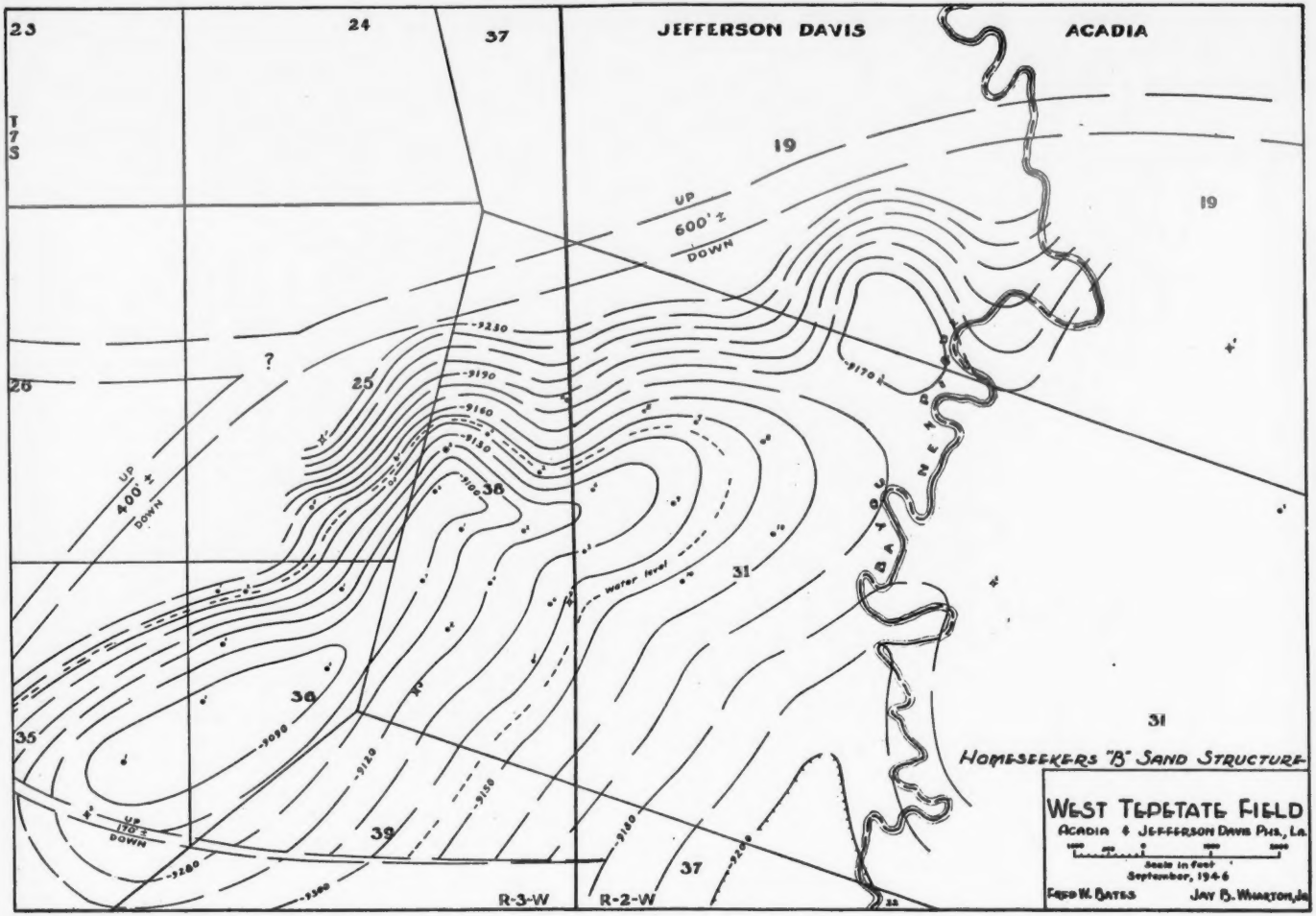


FIG. 6.—Structure contours on top of Homeseekers "B" oil sand.

Westward it apparently forks, with one limb striking southwest with 400 feet displacement, following the northwest flank of the structure. Its other trace is believed to continue due west toward the South Elton field. At West Tepetate, these major faults have not been confirmed by the drill, but the detailed geophysics accurately outlines their course and displacement. Nowhere do they intersect the known producing area.

Across the southwest nose, a smaller east-west fault, also upthrown on the north, crosses and affects the producing area. This fault has been noted in most of the southwestern field wells, and is shown to die out toward the east.

Dips are gentle south of the axis of folding; much steeper toward the north and northwest into the fault planes. Drilling, together with the geophysics, provides ample subsurface control to outline accurately the productive limits of the several reservoirs. Uplift is assumed to be caused by deep-seated salt intrusion, although none has yet been encountered.

The structural pattern presented is normal for this trend, and has often been called a "Tepetate-type" structure. Electrical and paleontologic correlations above a depth of 7,000 feet, or approximately the *Heterostegina* zone, are indefinite, with little uplift apparent from this time to the present. Structure contour maps were prepared on various horizons from this point down to the greatest depths penetrated, of which several are here presented. Figure 4 shows structure contours on the top of the *Heterostegina* zone; Figures 5 and 6 give the deeper structure at the level of two of the principal oil reservoirs, with the productive areas outlined by the water level on each. This series shows, with increasing depth, significant change in the amount, position, and configuration of the uplift.

FIG. 6.—Structure contours on top of Homeseekers "B" oil sand.

STRUCTURAL HISTORY

During the period when the oldest penetrated sediments were being deposited (Chickasawhay), there was apparently present an area of local structural uplift (or some other factor causing anomalously thin stratigraphic intervals) south or southwest of the field. As shown by the isochore, or convergence, map on the Klumpp "A"-Homeseekers "B" sand interval (Fig. 7), there was an increasingly thick series of sediments being deposited north from this high area. This thickening of section toward the north is the reverse of the normal regional condition in this area. The sediments of this interval (8,500–9,100 feet below the present surface) show an increase of more than 100 feet in thickness from south to north, and indicate the presence of a slight nose extending north over the region of the present producing structure.

During the next interval figured, between *Heterostegina* zone and Klumpp "A" sand time (Fig. 8), the relief changed considerably. The high area is farther north, centering in Section 38, with noses extending southwest and east. Within these time limits, there was a variation from 1,410 feet of sediments over the high area to 1,480 feet in the low areas. One of the major effects of the abnormally thick section present on the northwest is the thick development of the Ortego sand (Fig. 3). The faulting noted, and the normal structural growth, appear to contribute equally to the variations in sedimentation and intervals.

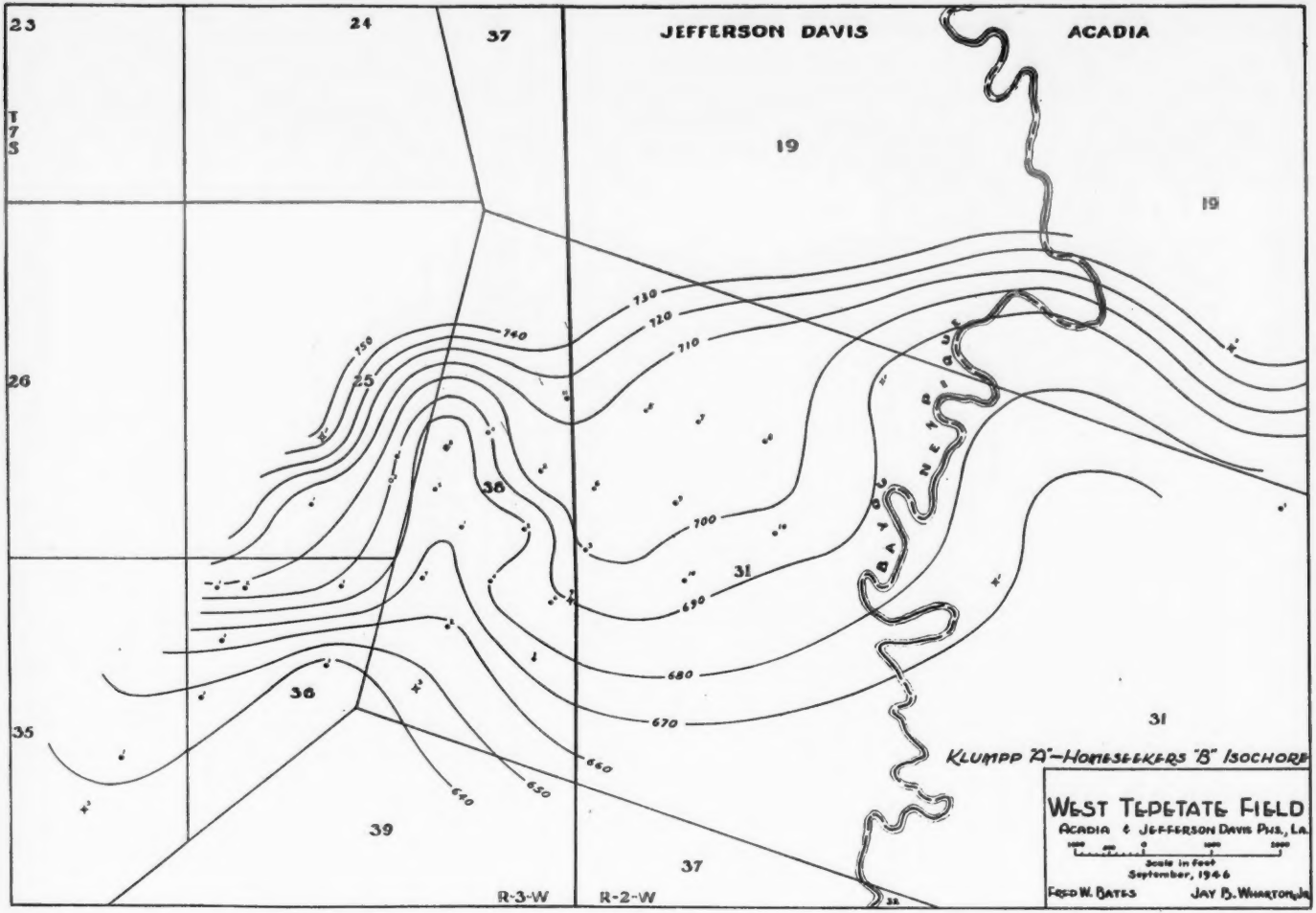


FIG. 7.—Isochore map of Klumpp "A"—Homeseekers "B" sand interval.

FIG. 7.—Isochore map of Klumpp "A"—Homeseekers "B" sand interval.

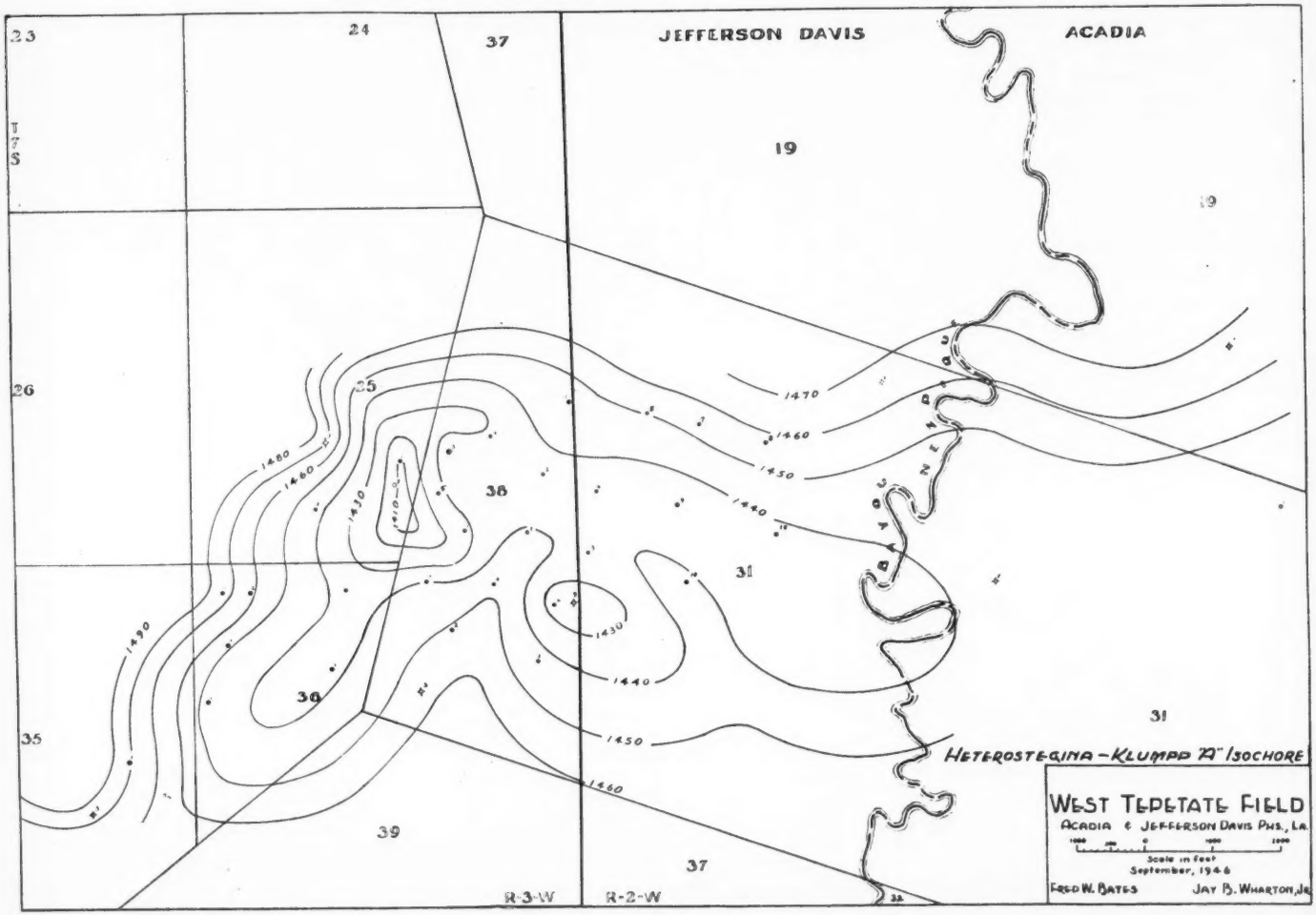


FIG. 8.—Isochore map of *Heterostegina* zone—Klumpp "A" sand interval.

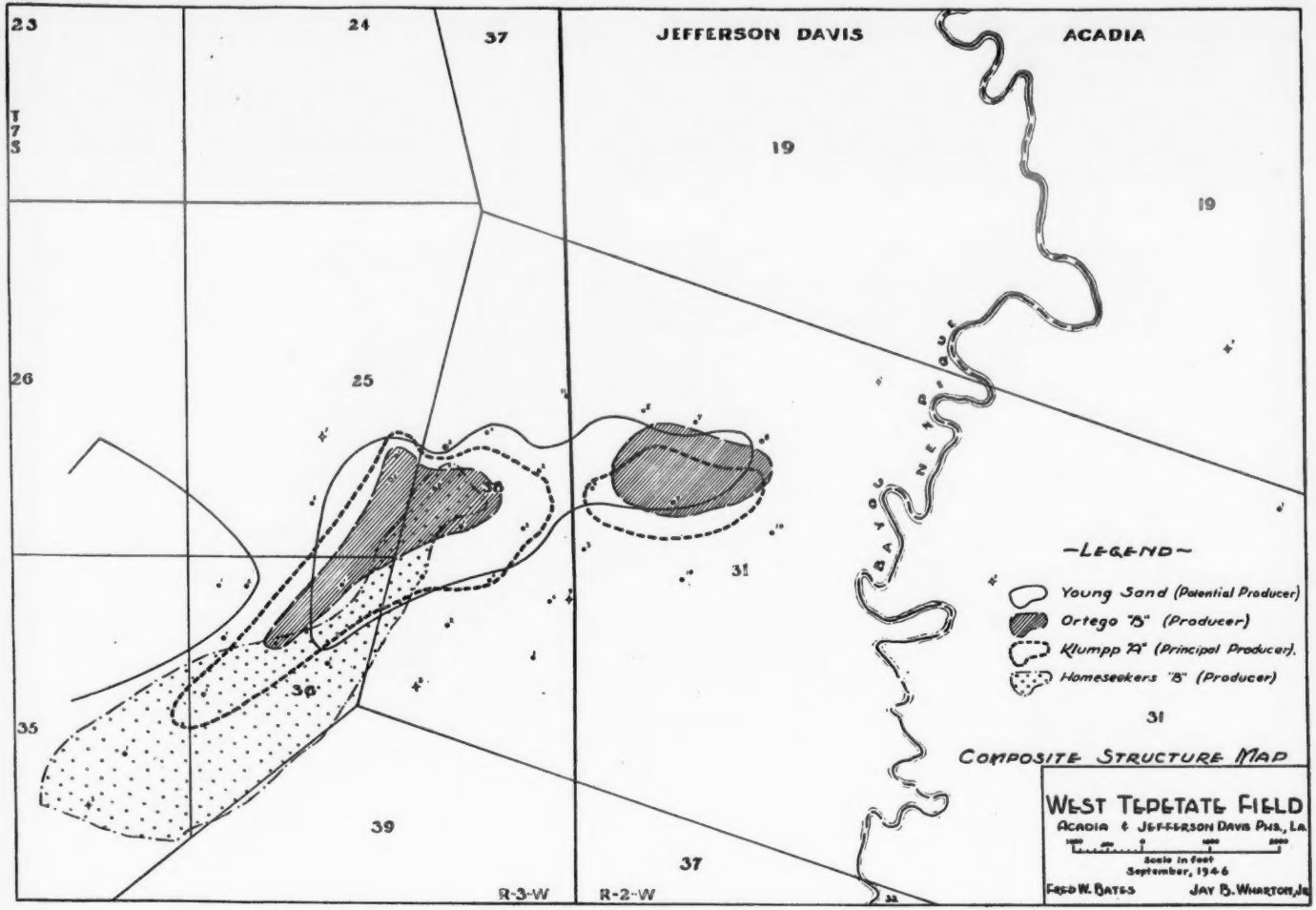


FIG. 9.—Composite structure map.

Figure 9 is drawn to show the comparison of the nature and location of structure at different times or depths. An approximately equivalent contour was taken from each of four structure maps, and superimposed on one base. From this composite can be seen a summary of the structural history of this area. The deepest level, Homeseekers "B" sand, shows a predominance of development on the southwest. At the Klumpp "A" sand level the structure has taken definite shape with only a nose extending southwest toward the deeper "high." At the Ortego "B" sand level the structure extends farther east and is broken into two highs, while the Young sand level is one broad east-west ridge with a supplemental dome on the west not previously indicated.

FIG. 9.—Composite structure map.

ESTIMATE OF RESERVES

From detailed isopach or net-sand maps the total effective volume of each reservoir (in acre-feet) was obtained by planimetering. A large volume of data was obtained on the reservoir characteristics and recoverable hydrocarbon content of the various sands by thorough core analyses. From this was derived a figure for each sand on the volume of recoverable oil and gas per acre-foot of effective reservoir. Based on the production history of similar sands in other fields on this trend, together with the physical characteristics and early production record of the reservoirs at West Tepetate, it was thought that water-drive would be highly effective. Later production characteristics have, however, conclusively shown that the water drive is greatly impeded, possibly by the faulting, and that recovery will be largely by gas expansion unless pressure maintenance of some sort is employed.

By multiplying the volume of each sand reservoir by its proper recovery factor, the reserve of recoverable hydrocarbons originally in place in the West Tepetate field was calculated to be 36,556,586 barrels of oil and 75,775,982 thousand cubic feet of gas (at atmospheric pressure). This figure for oil includes condensate from gas reservoirs, and the gas total includes solution gas from oil reservoirs. The crude averages 36° (A.P.I. gravity corrected).

SUMMARY

The development of the West Tepetate field has been normal and orderly on a 40-acre pattern. Early wells were drilled deep to secure subsurface data on all known producible sands. Subsequent wells were drilled to specific sands. Early attempts were made to complete dually, but this practice was found impractical; twin wells are now drilled where production from multiple sands on one unit is desirable. Thus far, about 1,400 acres have been found to be productive, with an indicated original reserve of more than 36 million barrels of recoverable liquid and about 76 billion cubic feet of gas.

It is doubtful if any attempt will be made in the near future to search for deeper oil, because regional stratigraphic studies indicate sand development at deeper levels is very poor. Additional development drilling may, however, make minor revisions necessary in the size and shape of the reservoirs now known.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1728-1749, 14 FIGS.

STRUCTURAL TRENDS AND FAULT SYSTEMS IN EASTERN INTERIOR BASIN[1]

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Ponca City, Oklahoma

ABSTRACT

The Eastern Interior basin is a structural basin cradled between the Ozark uplift and the Cincinnati arch-Nashville dome uplift.

The two most conspicuous structural features indicated by an areal geology map are the La Salle anticline and the nearly separated lobe of the basin in Kentucky. A cross section indicates that the area acquired its basin character early and retained it through most of geologic history.

A study of the folding and faulting within the basin reveals two different types of structure. One consists of a series of faults trending S. 20° W. and paralleling lines of anticlinal folding. Cross sections show these faults to be normal diagonal shears and the folds to be similar to the granite ridge and related lines of folding in the Mid-Continent area. The other is the Shawneetown-Rough Creek fault zone and associated faults extending across the south end of the basin.

Cross sections and data gleaned from the literature dealing with this and the Kentucky River fault zone, to which it appears closely related, show this to be an entirely different type of faulting from the system first described.

On the basis of the evidence presented, the writers suggest an explanation and classification of this zone of faulting different from any that has been proposed in the past.

The Eastern Interior basin is a structural basin cradled between the Ozark uplift on the southwest and the Cincinnati arch-Nashville dome uplift on the east and southeast, as shown on the areal geology map (Fig. 1). The basin proper includes the southern three-fourths of Illinois, western Indiana, and western Kentucky.

Pennsylvanian rocks cover the central part of the basin with Mississippian and progressively older rocks exposed around the margins. The Pennsylvanian strata include the important coal deposits of the southern Illinois and western Kentucky coal fields.

The upper Mississippian (Chester) beds do not crop out entirely around the basin, but thin toward the north and disappear in the vicinities of St. Louis and Terre Haute on the west and east flanks, respectively. The sands of the Chester, together with porous zones of the underlying Ste. Genevieve limestone, have produced the greater part of the oil recovered in the basin.

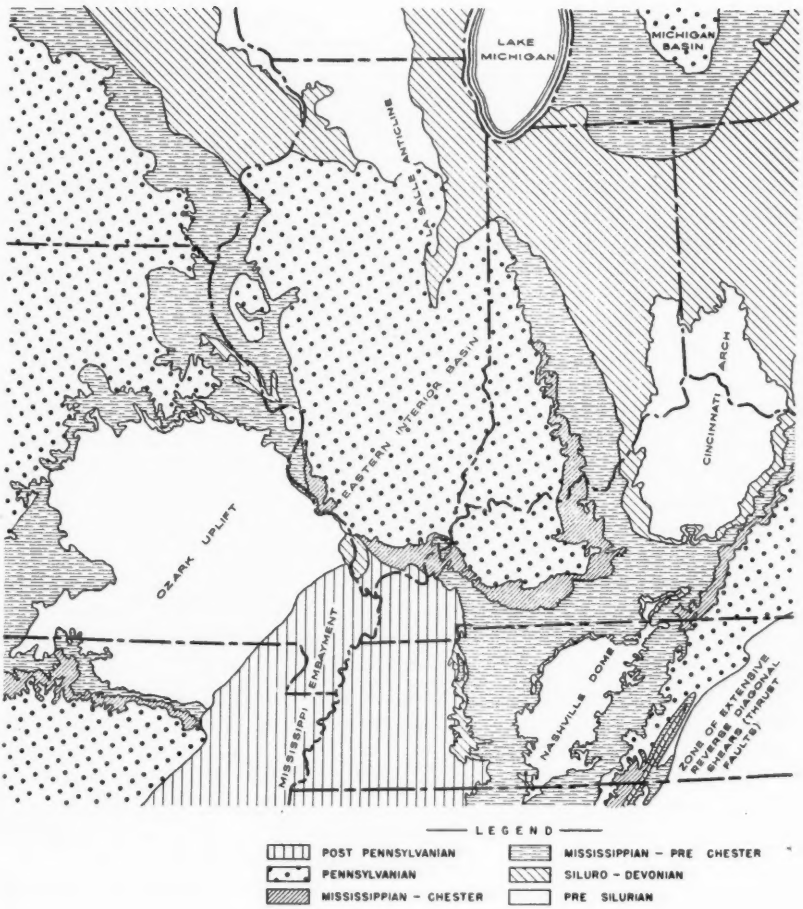
The areal geology map also reveals two of the outstanding structural features of the basin.

One is the La Salle anticline which extends into the basin in a direction about S. 20 E. as the gradually narrowing prong of the Wisconsin arch. The outline of the fold is partly obscured by overlapping lower Pennsylvanian beds.

Most of the oil produced during the first era of exploitation in Illinois came

[1] Read before the mid-year meeting of the Association at St. Louis, January 14, 1948. Manuscript received, June 4, 1948.

[2] Continental Oil Company. The writers are indebted to the Continental Oil Company for permission to publish this paper; to J. V. Howell, whose maps on the faulting in certain Illinois coal mines were an important source of information; and to George E. Taylor, who furnished information incorporated in the maps and cross sections of the Mount Carmel-New Harmony and Omaha dome areas.



AREAL GEOLOGY - EASTERN INTERIOR BASIN & SURROUNDING AREAS

FIG. 1

from fields related to the La Salle anticline. This great fold not only provided the structural conditions favorable for accumulation, but also brought the reservoir rocks, which lay at much greater depths in the adjacent basin, within reach of the shallow drilling depths then practicable. That fact, together with the lack of geological guidance of the industry at that time, probably explains the long hiatus between the first and second oil booms in Illinois.

The second significant structural feature indicated by the areal geological map is that most of the Kentucky part of the basin is a near-separate lobe with its axis extending in a direction about E. 20° S., in decided contrast to the north-south axis of the major basin.

The general geologic column present in the basin is shown on Figure 2. Details of the oil producing Chester section are shown as an expanded insert. Since this section has been described frequently, no further discussion of the strata is included.

A west-east cross section of the basin at the latitude of St. Louis is shown in Figure 3. The evident thinning of strata from the central part of the basin toward the margins suggests that the area acquired its basin character early and has retained it throughout most of geologic history.

The cross section also indicates the major unconformity between the Mississippian and Pennsylvanian strata. During this post-Mississippian, pre-Pennsylvanian hiatus, the basin was evidently simply the least active part of a broader area which was uplifted and tilted slightly toward the southeast. The pre-Pennsylvanian surface, however, was not reduced to a perfect peneplain. As a result, some of the folding mappable in the Pennsylvanian beds can be shown to be wholly or in part due to the presence of topographic features of the pre-Pennsylvanian surface (Louden in part).

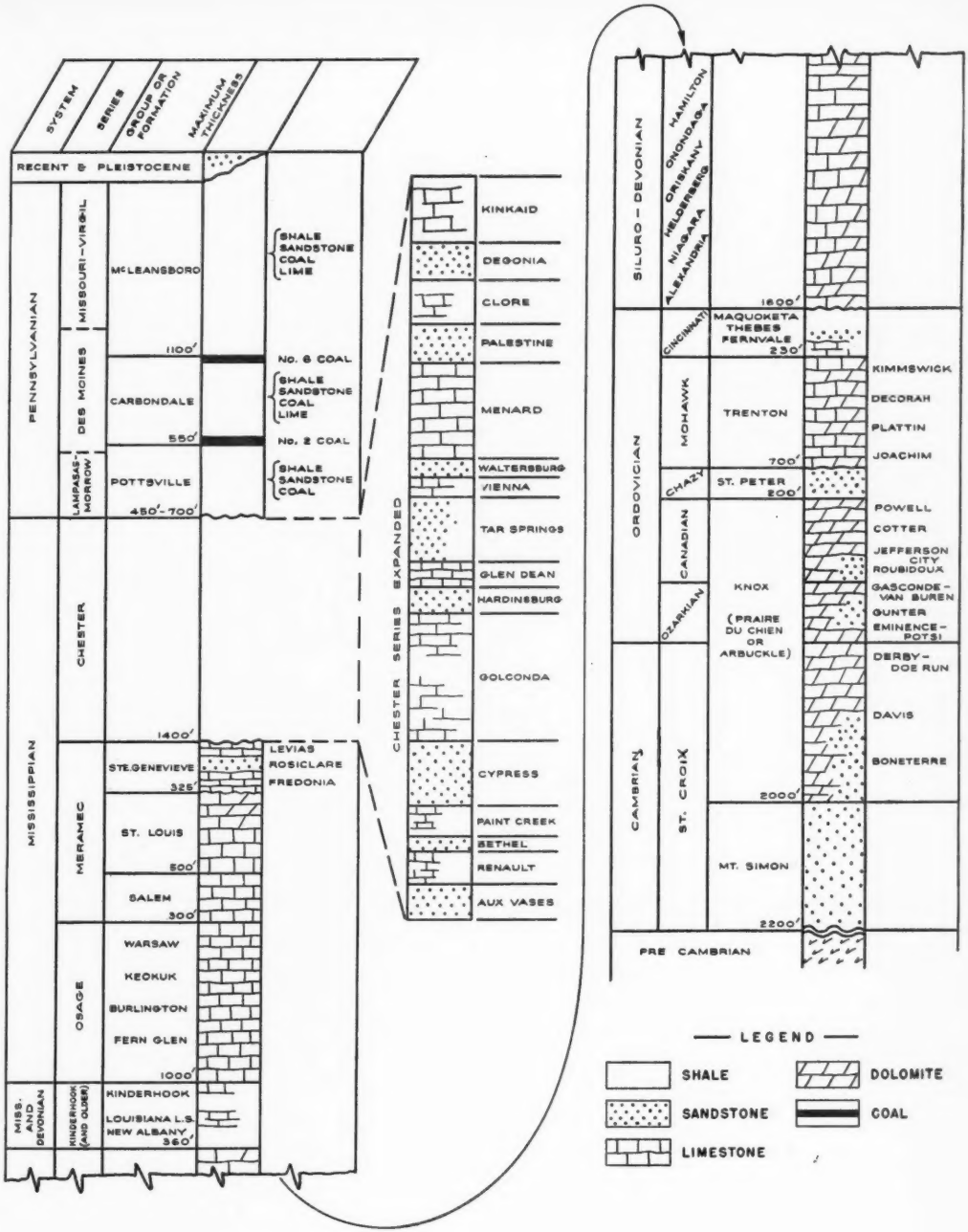
The general structure of the basin, as mapped on the top of the Ste. Genevieve limestone, is shown in Figure 4. Here also the La Salle anticline appears as the dominant positive feature; and although a relatively wide contour interval is used, the more important structural trends within the basin are evident.

The relationship of the semi-detached Kentucky part of the basin to the adjacent Rough Creek-Shawneetown fault system is also apparent from the structure map.

The pattern of folding and faulting in the basin is shown on Figure 5, on which the positions of the major anticlinal trends are indicated by lines designating their axes. The outlines of the oil- and gas-producing areas are also included in order to show the relationship of the producing fields to the tectonic features.

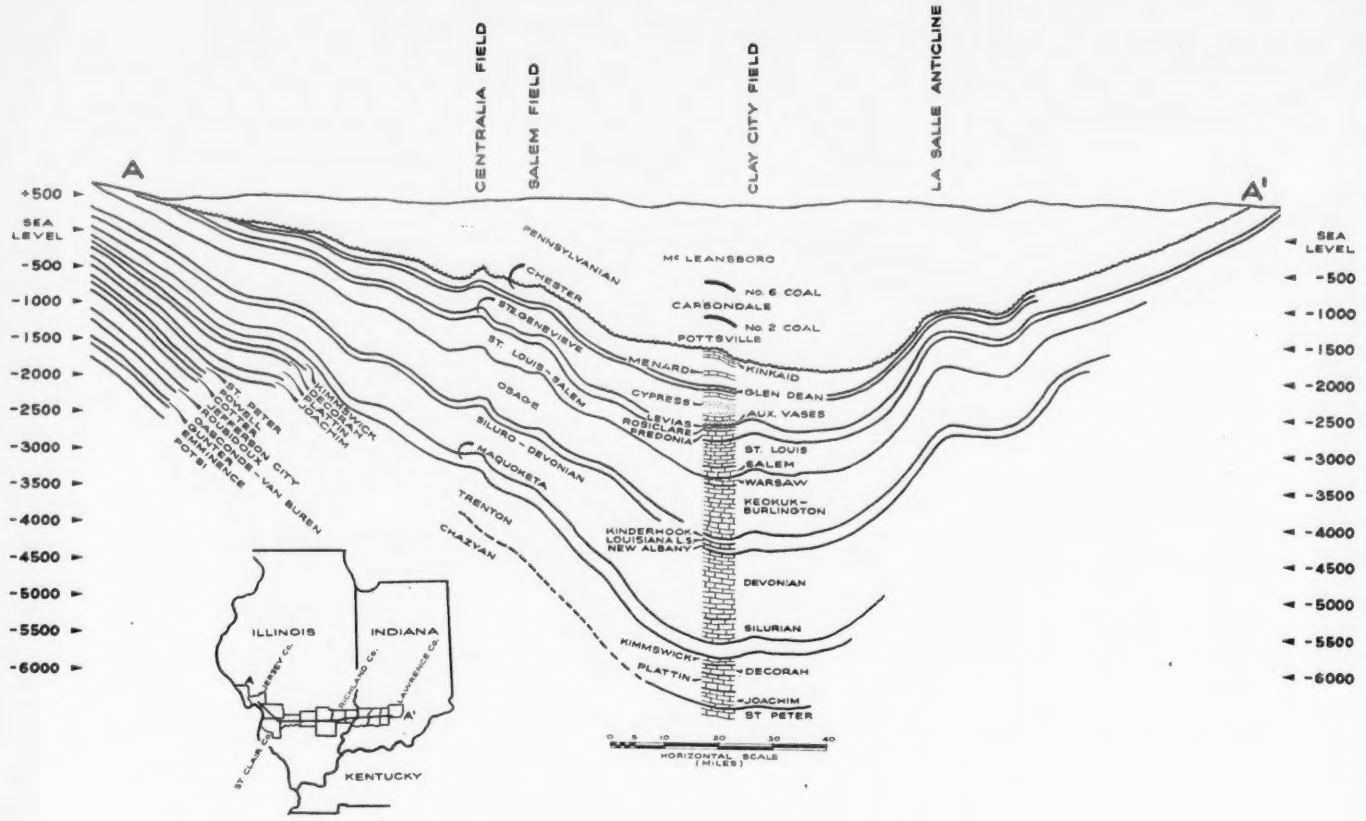
In the deeper part of the basin, the dominant features are the series of anticlines and faults generally trending about S. 20° W., in contrast to the southeastward trend of the La Salle anticline. The Duquoin flexure, however, extends almost due north and south. These folds are identical in type and parallel in alignment with those of the so-called granite ridge and similar lines of folding in Kansas and Oklahoma. The faults of this group are the familiar normal diagonal shears which occur commonly throughout the Mid-Continent and Gulf Coast regions.

Across the south end of the basin, another group of faults is found. This is the Rough Creek-Shawneetown fault zone. It is a complex system of faulting with a general eastward trend. Near its western end, however, the trend of the faulting changes to northeast and southwest. This is not only a different system of faults, but an entirely different type of fault.



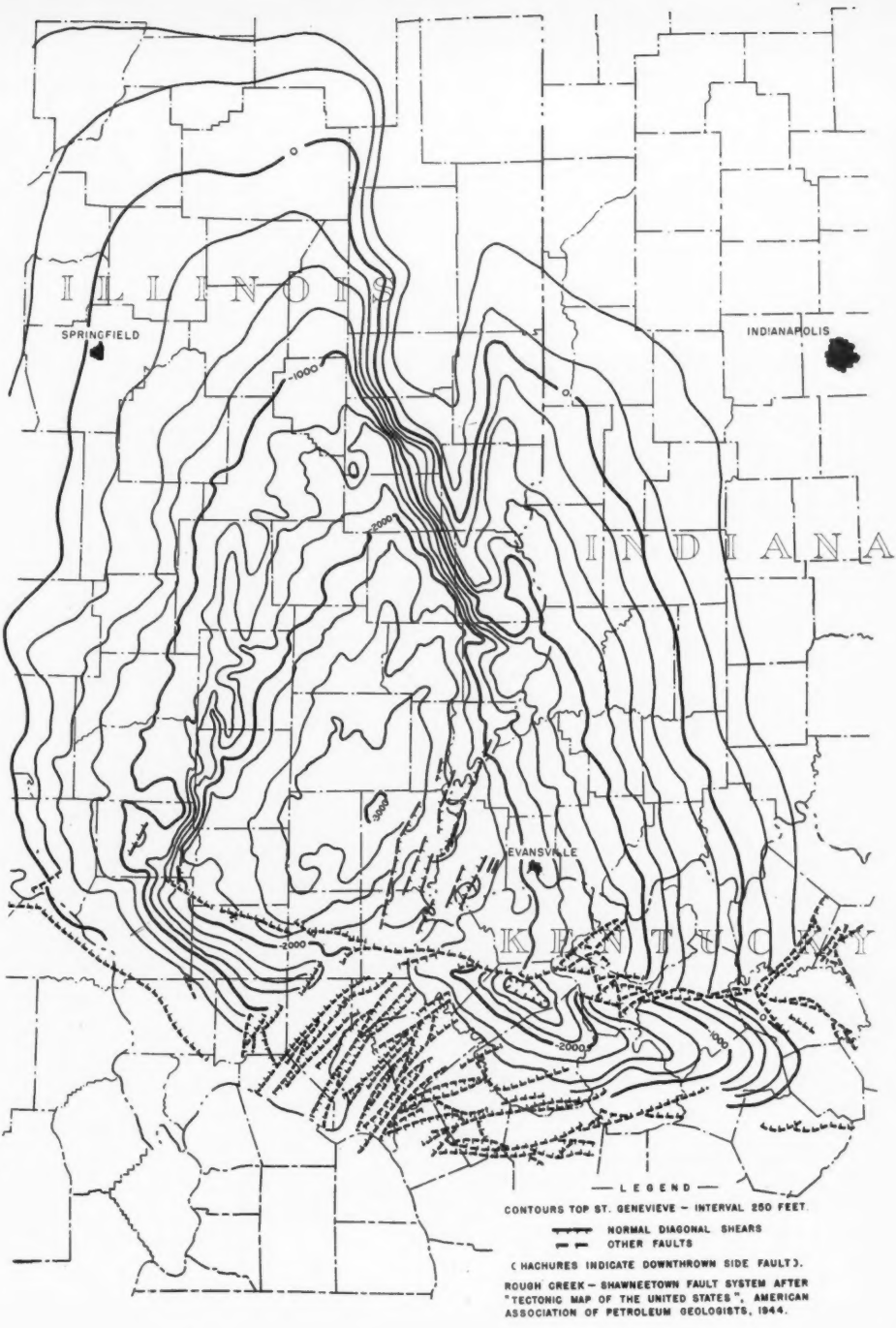
GENERALIZED STRATIGRAPHIC COLUMN - EASTERN INTERIOR BASIN

FIG. 2



WEST—EAST CROSS SECTION THROUGH EASTERN INTERIOR BASIN

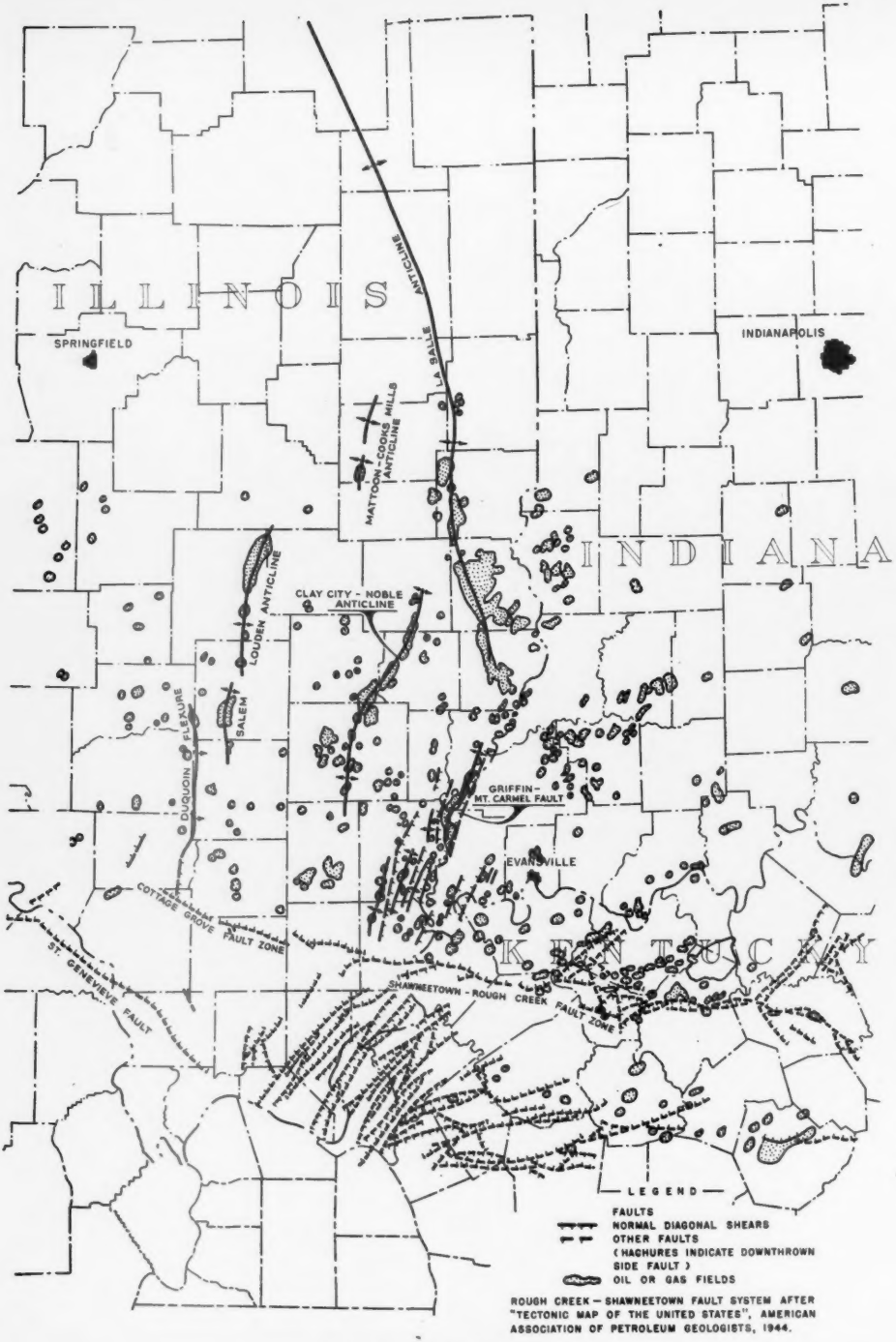
FIG. 3



STRUCTURE OF THE EASTERN INTERIOR BASIN

FIG. 4

FIG. 3



EASTERN INTERIOR BASIN
SHOWING
OIL FIELDS, FAULTS, AND AXES OF PRINCIPAL ANTICLINES

FIG. 5

Along the southwestern margin of the basin, another great fault, the Ste. Genevieve, divides the basin and the Ozark uplift for a considerable distance before zig-zagging into the margin of that uplift.

A study of the systems of S. 20° W. folds and faults in the central part of the basin shows the folds and adjacent faults to be nearly parallel, thus suggesting a close relationship. The arrangement of the anticlines along persistent lines of folding, here and there with slight offsets, *en échelon*, suggests that they probably follow old lines of faulting in the basement rocks.

FIG. 6.—Aerial photograph looking northeast along fault in pre-Cambrian rocks extending 80 miles northeast from Hornby Bay, Great Bear Lake. By permission of Royal Canadian Air Force.

Aerial photographs of two faults in the basement rocks of the Canadian shield are furnished by the Royal Canadian Air Force (Figs. 6 and 6-A).

Figure 6 is a view looking northeast along a fault in pre-Cambrian rocks extending 80 miles northeastward from Hornby Bay, Great Bear Lake. The rocks include late pre-Cambrian sandstone on the left and early pre-Cambrian granite and granite porphyry on the right.

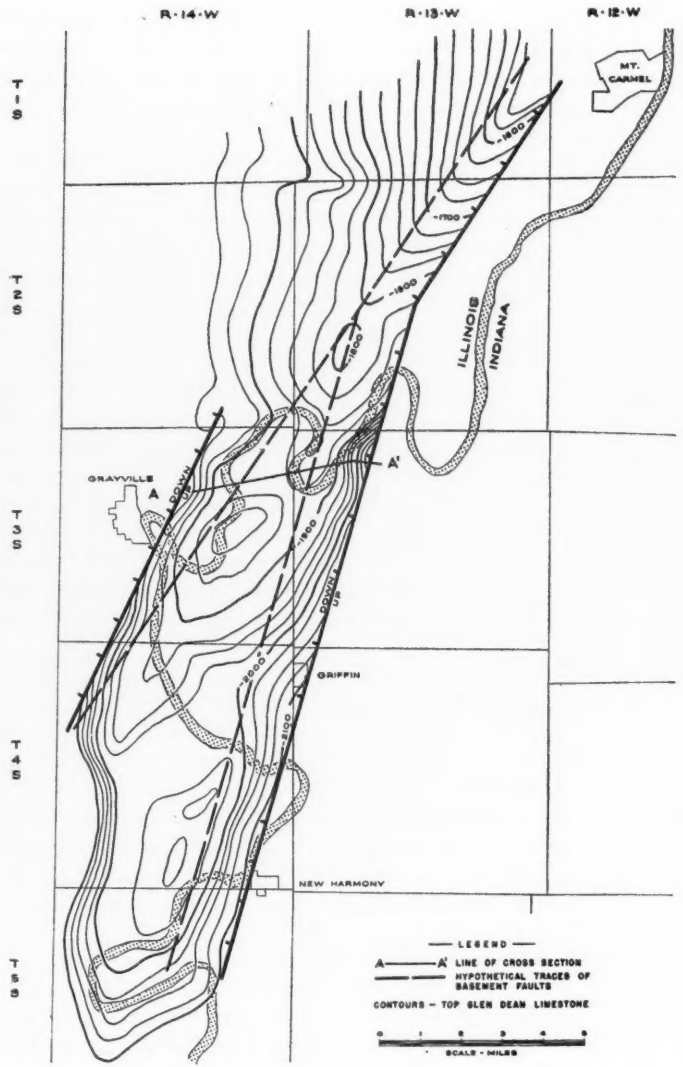
Figure 6-A is a view southwest along a large fault south of the east arm of Great Slave Lake. The rocks include early pre-Cambrian granites in the left

background and late pre-Cambrian conglomerates, sandstones, and diabase in the foreground. Both pictures help to visualize the manner in which such basement faults and the associated topographic features might subsequently affect the structure of sediments deposited above the present surface. The second picture, in particular, with its topographic high terminating abruptly at the fault scarp, undoubtedly provides a perfect illustration of the appearance of the core of

FIG. 6A.—Aerial photograph looking southwest along fault south of east arm of Great Slave Lake. By permission of Royal Canadian Air Force.

a typical large closed anticline of the "granite ridge" type. The other picture gives an idea of the complications that might appear in a structural condition resulting from renewed movement on a basement fault plane in a locality where the topography of the basement is not dominated by the effects of the major fault.

A detailed part of the aforementioned area of parallel faults and anticlines in the central part of the basin is shown in Figure 7. The illustration depicts part of the Mt. Carmel-New Harmony fault on the east, a shorter fault near Grayville on the west, and the structure of the intervening folding as contoured on the Glen Dean limestone.



MT. CARMEL – NEW HARMONY FAULT AND ADJACENT FOLDING
WABASH COUNTY, ILLINOIS – GIBSON COUNTY, INDIANA

FIG. 7

The line of folding is on the downthrown side of the Mt. Carmel-New Harmony fault and is nearly parallel with it. The folding is anticlinal throughout and generally plunges southward, with local closures along the axis. The Mt. Carmel-New Harmony fault appears to be continuous, with one marked change of direction for a distance of more than 20 miles.

If the fault is projected downward along the measured angle of dip, it would intersect the basement rocks along a trace shown by the heavy dashed lines. And if the axial planes of the anticlinal folding remain essentially vertical—as mapped on the horizons penetrated by drilling—the traces of these axial planes would intersect the basement rocks along virtually the same lines. We may assume, therefore, that the line of anticlinal folding is an effect of deep-seated faulting in the basement rocks—probably of similar nature to that shown in Figure 6-A. It is also probable that the faulting in the basement rocks branches at a point opposite the change of strike of the fault trace as mapped on the Glen Dean horizon.

The line AA' represents the trace of the cross section as shown in Figure 8. This illustration shows the character of the Mt. Carmel-New Harmony fault and its position in relation with the anticlinal folding. At this locality the fault consists of two distinct fractures, identifiable by losses of section in the wells which pass through them. One of these fractures disappears upward before reaching the shallowest mappable marker horizon. The upthrown side of the fault is on the east, and the fault plane dips west at an angle of approximately 55° or a hade of 35°.

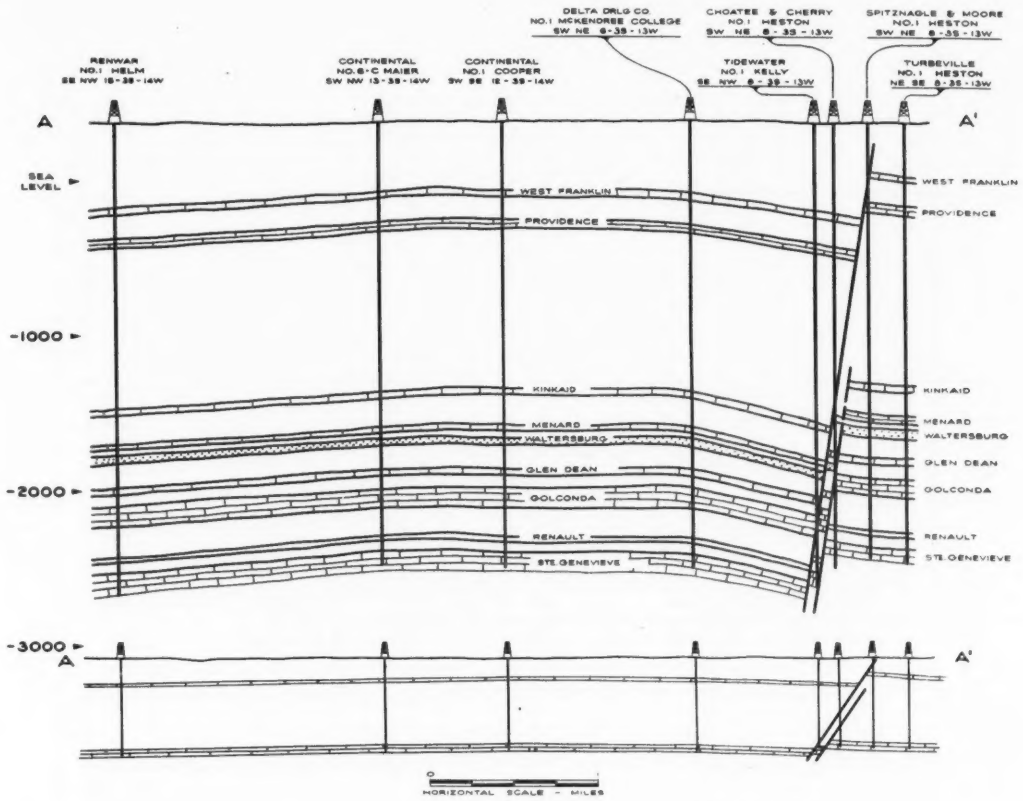
It may be noted that this fault satisfies all the criteria for the identification of a normal diagonal shear in that: (1) vertical holes drilled through it encounter a loss of section equal to the vertical displacement; (2) the fault plane is inclined 55° from the horizontal; and (3) the fault is of deep-seated origin, and shows a tendency to die out upward.

Figure 9 presents a cross section through the Omaha dome and a fault which occurs east of that fold. In this instance, the trace of the fault on a shallow marker is also east of the anticlinal axis. But, with the upthrow on the west, the fault plane dips east and is progressively farther from the axial plane of the fold with increasing depth.

In other words, this fault and this anticline could not have had a common origin at depth.

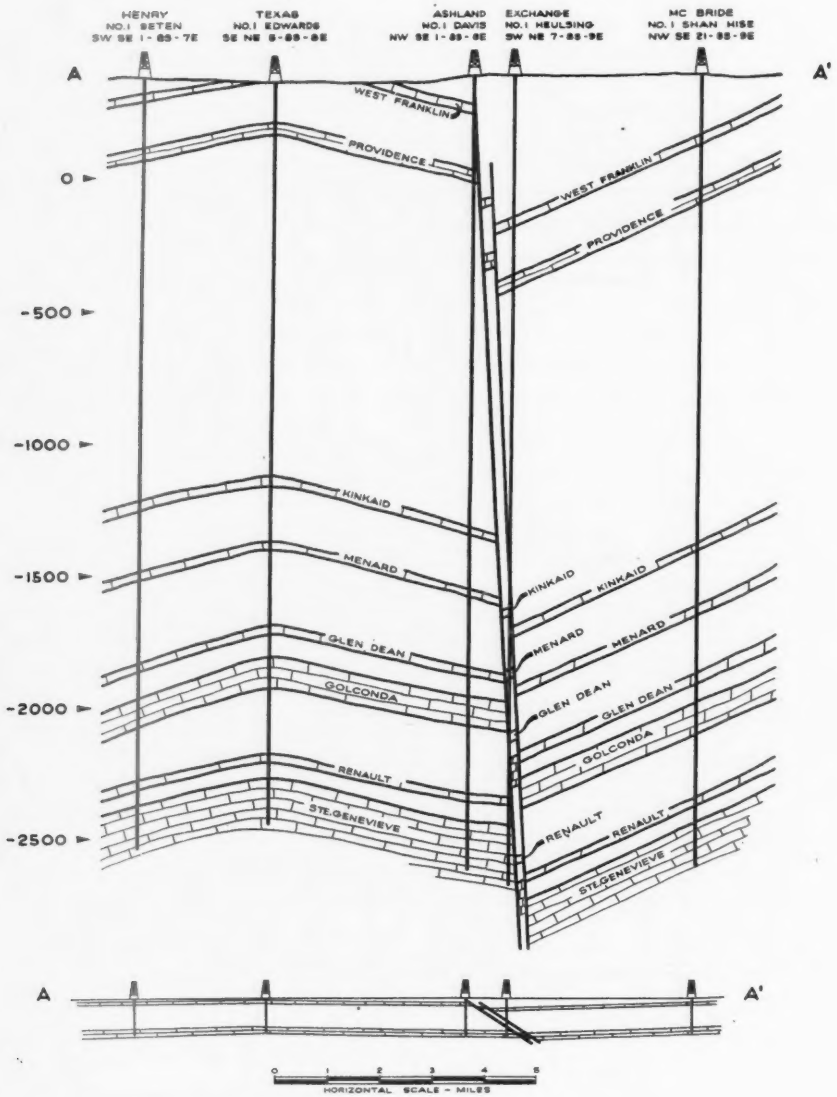
Faults of this type have been pictured so frequently in the records of oil-field geology that additional illustrations of the system of S. 20° W. faults in the basin seem unnecessary.

In the south end of the basin, it may be noted that the Rough Creek fault zone marks the northern boundary of a wedge-shaped area extending 175 miles from east to west. It is 50 miles wide near the western end and tapers to half that width near the eastern end. The north and south boundaries are marked by almost continuous faulting, but the eastern two-thirds of the interior of the wedge



WEST — EAST CROSS SECTION
GRIFFIN FIELD
GIBSON COUNTY, INDIANA

FIG. 8



WEST — EAST SECTION ACROSS
OMAHA DOME
GALLATIN COUNTY, ILLINOIS

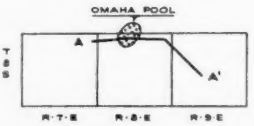


FIG. 9

is relatively free of faulting. However, at the western end, intensive faulting extends all the way across the wedge in a belt about 40 miles wide. In that belt, the faulting bends around to a northeast-southwest alignment; extensive mineralization has occurred along the fault planes; and small igneous intrusions have occurred.

The nature of this faulting had been somewhat of an enigma to the writers, but the preparation of this paper forced the undertaking of studies which resulted in an accumulation of sufficient data to justify suggesting a classification.

Many of the references are confusing in that the faulting is variously designated as a zone of thrust faulting; or predominantly thrust faulting, overthrust from the south; whereas, elsewhere it is designated as normal faulting. The term "block faulting" also appears frequently.

The Tectonic Map of the United States, published by the A.A.P.G. (1944), shows the north boundary fault of the zone as a "high-angle reverse fault." The other faults are shown by a symbol indicating "normal fault, or undifferentiated high-angle fault."

The complete assemblage of evidence suggests that the confusion as to type probably has its origin in the attempt to classify all faults as either normal or reverse, and the further assumption that any degree of reverse hade of a fault plane, no matter how slight, warrants the use of the terms thrust or overthrust.

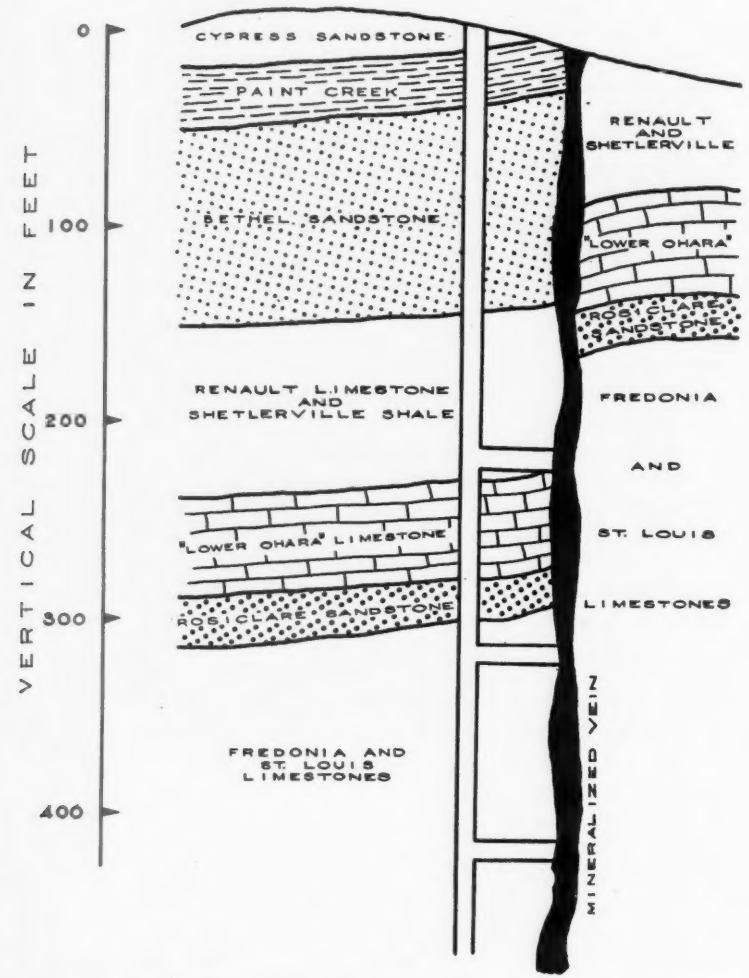
The most explicit information comes from the fluorspar mining area in southern Illinois where shafts sunk to work the mineralized veins along the fault planes have made precise data available. Figures 10, 11, and 12 show cross sections of the faults at three of these shafts.

Many geologists have objected to the attempts of the senior writer to set up a classification of faults on the basis of the mechanics of the failure, one of the arguments advanced being that faults do not fall into distinctly different classifications. However, even the most casual inspection of the faults pictured in Figures 10, 11, 12 suggests that they are of an entirely different type from the normal diagonal shears previously shown, or from the reverse diagonal shears (low-angle thrust faults) of the Appalachian area.

Consequently, an attempt to classify the faults of this group does seem warranted. Their most obvious characteristic is that the fault planes are essentially vertical. A precisely vertical fault plane does not fit the definition of either a normal or a reverse fault; and for classification purposes those terms become meaningless and confusing when applied to faults which closely approach the vertical.

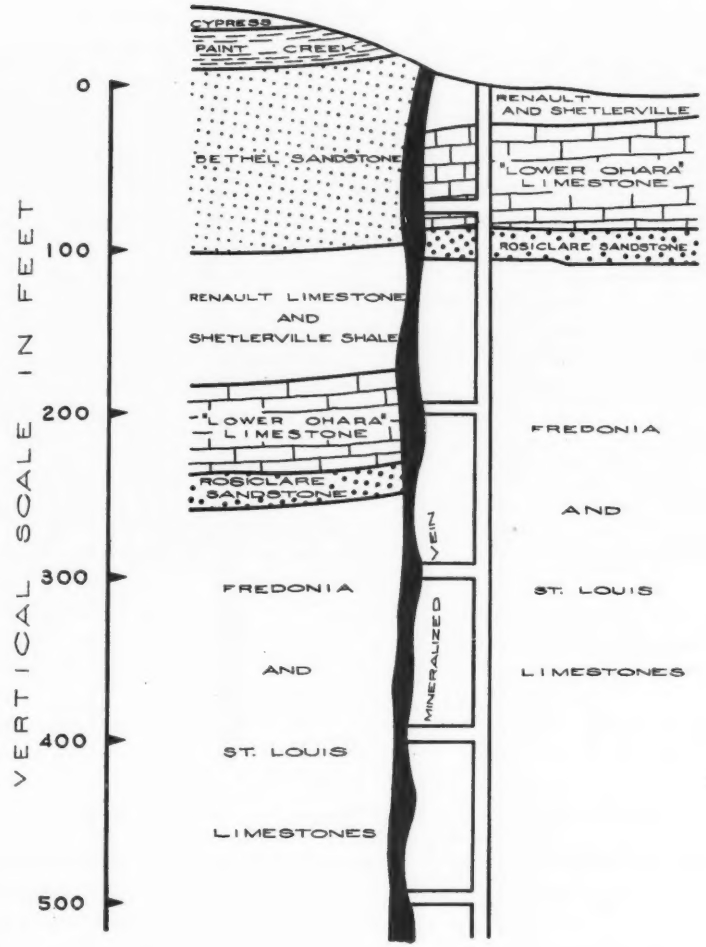
L. W. Currier[3] says, "The Good Hope-Rosiclare vein is nearly vertical, here and there changing in inclination from steeply west to steeply east." In other words, the fault wanders from "normal" to "reverse," if those terms are to be applied.

[3] L. W. Currier, "Geology of Hardin County," *Illinois Geol. Survey Bull. 41*, pp. 250–52.



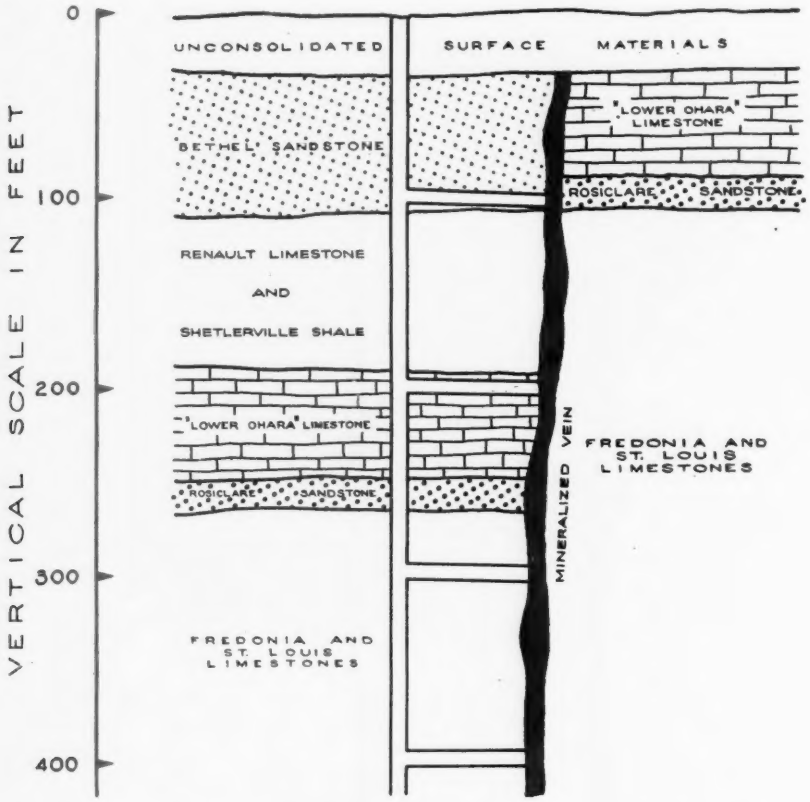
IDEALIZED GEOLOGIC SECTION THROUGH THE AIR SHAFT OF THE ROSICLARE MINE
HARDIN COUNTY, ILLINOIS
(FROM "GEOLOGY OF HARDIN COUNTY", ILLINOIS STATE GEOLOGICAL SURVEY, BULLETIN 41)

FIG. 10



IDEALIZED GEOLOGIC SECTION THROUGH THE NEW GOOD HOPE MINE SHAFT
HARDIN COUNTY, ILLINOIS
(FROM "GEOLOGY OF HARDIN COUNTY", ILLINOIS STATE GEOLOGICAL SURVEY, BULLETIN 41)

FIG. 11



IDEALIZED GEOLOGIC SECTION THROUGH THE ANNEX MINE SHAFT
HARDIN COUNTY, ILLINOIS
(FROM "GEOLOGY OF HARDIN COUNTY", ILLINOIS STATE GEOLOGICAL SURVEY, BULLETIN 41)

FIG. 12

That this near verticality of the fault planes is not confined to the mineral mining area is attested by J. V. Howell,[4] who has studied the faulting in a number of southern Illinois coal mines, and by the persistent appearance of the term "high angle" in descriptions of the faulting from practically all sources.

There is both direct and indirect evidence of lateral movement along these fault planes.

[4] J. V. Howell, oral communication.

The direct evidence consists of horizontal slickensides found in some of the mineral mines. Currier[5] says:

> The lenticular shape of the large veins is attributed to the slightly undulatory character of the fault fissure and the fact that the walls underwent a slight horizontal movement . . . *Indications of slight horizontal movement are found in nearly horizontal striations of slickensides on the vein walls.* Such striations are particularly well developed in the Annex and Rosiclare mines.

No reason is mentioned for designating the lateral movements along the fault planes as slight and, in view of the difficulty of detecting and measuring such displacements in relatively flat strata as contrasted to the ease of measuring the vertical displacements, perhaps we would be justified in placing a mental question mark after the word slight.

The indirect evidence indicating lateral displacement along the fault planes includes the development of open fissures already cited, in which thick vein deposits accumulated. In the presence of such lateral movement, any change in the direction of the fault tends to result in the development of open fissures.

The presence of open fissures is in marked contrast to the conditions that exist in normal diagonal shearing where there are strong force components normal to the fault plane, forcing the materials on opposite sides into contact. Such faults have provided notably effective seals against the further movement of oil and gas in a great many instances.

The presence of scissors faults also constitutes evidence pointing toward lateral displacement. The fault indicates sufficient shearing stress to produce a failure, yet the vertical displacement is up on one side along part of the length of the fault, but reverses and is up on the opposite side. At the point of reversal, the vertical displacement is, of course, zero.

Examples of scissors faulting have been published. Several of them are shown in Figure 13, which is a simplified drawing after Weller.[6] Faults indicating the scissors effect are shown by heavy trace lines. These occurrences are notable because of the repetition of the scissors effects along the same faults.

Another case of scissors faulting was reported by the Kentucky Geological Survey, the occurrence being in the Skybo mine.[7]

Three more occurrences of the scissors effect on individual faults are shown in Figure 14, which shows in detail the patterns of faulting in the mines of the Southern Illinois coal field. Hachuring supplemented by heavy lines is used to indicate the downthrown sides of the scissors faults. The information on this illustration was all furnished by J. V. Howell and is based primarily on his

[5] L. W. Currier, *op. cit.* Italics are by the present writers.

[6] J. Marvin Weller, "Geology and Oil Possibilities of Extreme Southern Illinois," *Illinois Geol. Survey Rept. Inves. 71* (1940).

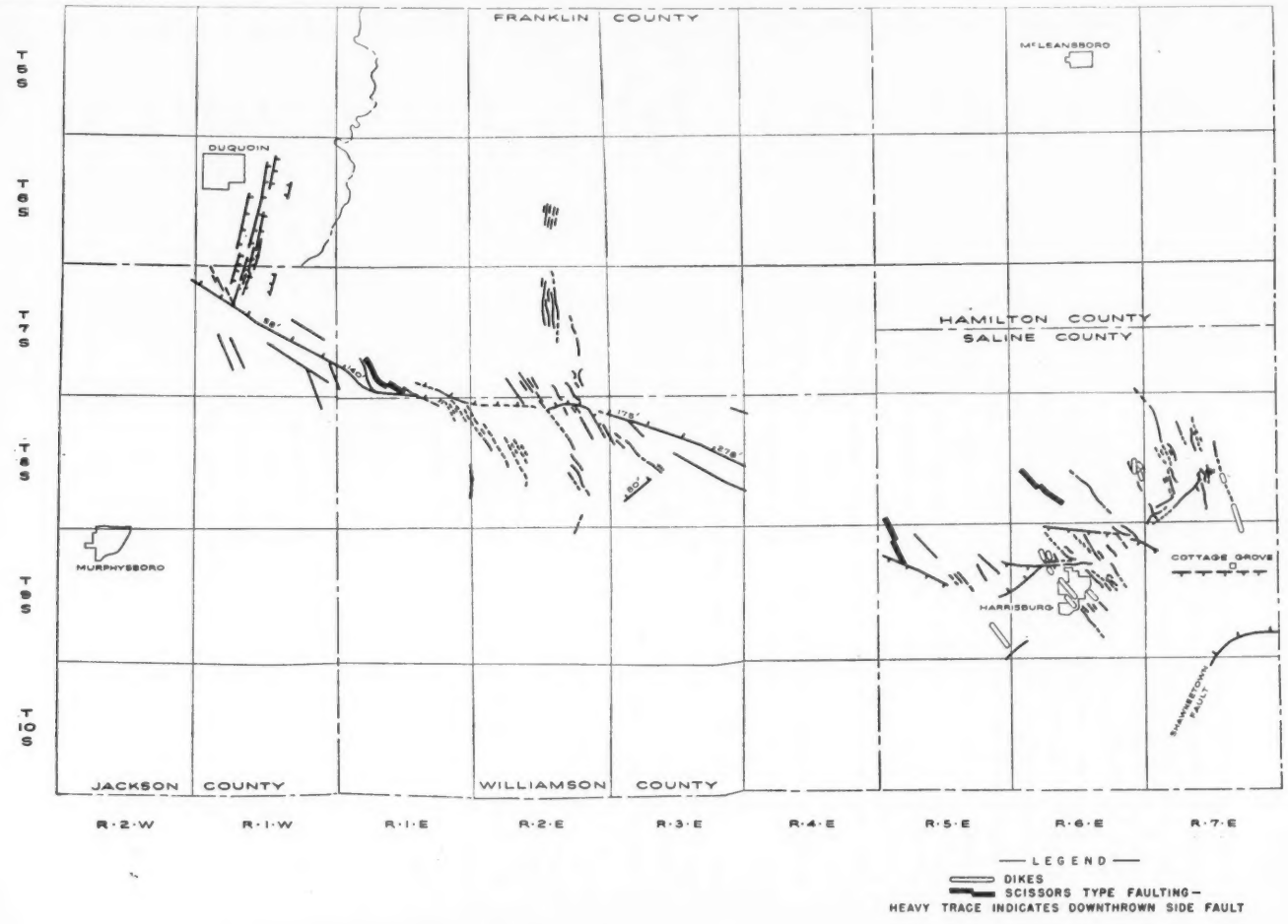
[7] "Geology and Coals of Central City, Madisonville, Calhoun, and Newberg Quadrangles," *Kentucky Geol. Survey Bull. 19*, Ser. 26, p. 8.

— LEGEND —
FAULT WITH HACHURES ON DOWNTHROWN SIDE.
SCISSORS TYPE FAULTING — HEAVY TRACE INDICATES DOWNTHROWN SIDE FAULT.
STRUCTURE CONTOUR MAP OF
EXTREME SOUTHERN ILLINOIS
(FROM PLATE I, ILLINOIS STATE GEOLOGICAL SURVEY,
REPORT OF INVESTIGATIONS NO. 71, 1940, BY J. MARVIN WELLER.)
STRUCTURE CONTOURS ON VARIOUS MISSISSIPPIAN & PENNSYLVANIAN HORIZONS.
JOHNSON CO.
MASSAC CO.
POPE CO.
MASSAC CO.
POPE CO.
OHIO RIVER
FRANKLIN COUNTY
R 3 E
R 4 E
R 5 E
R 6 E
R 7 E
R 8 E
R 9 E
T 15 S
T 14 S
T 13 S
T 12 S
T 11 S

FIG. 13

STRUCTURE CONTOURS ON VARIOUS MISSISSIPPIAN & PENNSYLVANIAN HORIZONS.

FIG. 13



COTTAGE GROVE AND DUQUOIN FAULT ZONES

AS MAPPED FROM COAL MINE AND CORE HOLE DATA

FIG. 14

studies of the mining company's maps of the area. The fact should be kept in mind that the precise control provided by the coal-mine surveys makes it possible to map faults that for the most part would otherwise be undetectible. In other words, much of the faulting shown is of an entirely different order of magnitude from that shown in the other illustrations.

The most persistent zone of faulting shown is that extending from Cottage Grove and Harrisburg on the east to a point about 5 miles south of Duquoin. It has approximately the same alignment as the Rough Creek-Shawneetown zone and probably represents an extension of that trend, with greatly diminished intensity, beyond the point where the major zone turns southwest. Faulting is assumably continuous along the Harrisburg-Royalton zone, lack of mine control being the cause for the apparent gap in Range 4 East.

Vertical displacements along this main zone attain a maximum of 278 feet. The zone as a whole constitutes a great scissors, in that the vertical displacements east of Range 4 East are predominantly down on the south, while those on the west are predominantly down on the north.

Vertical displacements are negligible on many of the smaller faults mapped. (Hachuring has been omitted since the displacement is not significant.)

The fault planes are reported to be essentially vertical.

In the general vicinity of Harrisburg, a number of dikes have been found, all of which occur along northwest-southeast faults that make an angle of about 45° with the main zone.

Another zone of nearly north-south faulting is shown in the vicinity of Duquoin. The zone consists of a series of parallel faults, located on the steep east limb of the Duquoin flexure and predominantly downthrown on the east. The fact that it consists of a series of faults, rather than one large break, probably accounts for the difficulty in establishing the deformation as faulting in subsurface mapping based on well control alone.

A summary of the character of the Rough Creek-Shawneetown fault zone follows.

Viewed in broad perspective, the Rough Creek-Shawneetown fault zone and the associated faulting on the south constitute a zone of shearing with a maximum width of 50 miles and a length of 175 miles. There is some evidence suggesting that the Kentucky River fault zone is a continuation of this zone extending to the West Virginia border, in which case the over-all length is 400 miles. The zone was subjected to forces sufficient to produce a complex series of faults, which manifest a tendency to slice the sheared zones into a series of narrow, sliver-like blocks.

Obviously, this is no minor structural feature but one of regional extent. However, there is no major uplift paralleling the zone on one side, and major depression on the other, as a possible cause for such a shear zone.

If we turn to the fault zone itself for clues about its origin, we find the faults repeatedly described as "high angle"; and, where specific information is available, that term may be translated as meaning "essentially vertical."

While vertical displacements ranging as high as 2,000 feet or more are reported, there is no systematic upthrow in one direction. The vertical displacements are not only indiscriminately up and down within the zone as a whole, but many instances of scissors faulting in which the direction of vertical displacement reverses within the length of an individual fault are known. There is also both direct and indirect evidence of horizontal movement along the fault planes.

On the basis of this evidence, we advance the thesis that the general Rough Creek and associated fault zones probably represent a zone of lateral shearing similar to the San Andreas fault in California, and that the vertical displacements, great as some of them are, are simply the incidently crowding up or dropping down of the sliver-like slices created by the lateral shearing.

Since the faulting in this case is pre-Tertiary in age, the more obvious evidences of lateral displacement, such as the abrupt displacement of stream channels, found along the San Andreas fault as the result of recent movements, have all disappeared.

However, lateral shearing, with westward movement of the northern border of the zone relative to the southern border, may explain the bending of the axis of the Kentucky lobe of the basin around to east and west.

That same westward movement impinging against the northeast flank of the mass of the Ozark uplift may explain the intensification of the faulting near the western end of the zone; the bending of the faults into a northeast-southwest alignment; the consequent development of more open fissures; and thus the localization of the fluorspar mining industry in the western end of the zone.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1750-1761, 1 FIG.

STRATIGRAPHIC RELATIONS OF CERTAIN JURASSIC FORMATIONS IN EASTERN MEXICO[1]

RALPH W. IMLAY,[2] EDMUNDO CEPEDA,[3] MANUEL ALVAREZ,[3] AND TEODOR DIAZ[3]

ABSTRACT

Certain Jurassic formations of Mexico are defined and their probable correlation and origin discussed. Marine Lower Jurassic (Lias) rocks cropping out in the mountains of northern and central Veracruz, eastern Hidalgo, and northern Puebla are named the Huayacocotla formation. The overlying redbeds are named the Huizachal formation and are compared with the Upper Jurassic Eagle Mills formation of the southern United States. Evidence of general erosion and local strong folding of the Huizachal formation prior to upper Oxfordian time suggests that similar events may have occurred elsewhere in the Gulf region and may have had a bearing on the origin of Upper Jurassic salt in southern Mexico.

INTRODUCTION

During the last three months of 1947, the writers had the opportunity of examining many outcrops in the mountains bordering the Huasteca area of Veracruz, Hidalgo, and Puebla and in the area between Victoria, Tamaulipas, and Catorce, San Luis Potosí. These studies led to considerable discussion concerning the origin and stratigraphic relationships of the various formations and the desirability of establishing names for the rock units previously referred to generally as marine Lias and redbeds. It was felt that defining these units would clarify future discussions concerning them and would simplify usage for commercial geologists. Also, description of the rock units should contribute toward a better understanding of the history of the Gulf of Mexico.

The conclusions presented are not based merely on 3 months of field work. Edmundo Cepeda has spent more than 2 years mapping in the area. Besides, the writers had access to various reports made by geologists of the Mexican Eagle Oil Company, including especially Hans Jenny, W. R. Fehr, E. G. Bonnard, and Arnold Heim. Proper credit to these geologists is given in the text.

Many thanks are due to the officials of Petróleos Mexicanos for permission to publish some of the most interesting information concerning the Jurassic of Mexico. In particular, thanks are due Manuel Rodriguez-Aguilar, chief of the exploration department, for his frank discussions of the geologic problems involved, for his helpfulness in expediting the field work, and for his friendly criticism of this manuscript.

HUAYACOCOTLA FORMATION

Definition.—The Huayacocotla (pronounced Wī-a-kō-kōt′-la) formation is herein defined as the 1,000–1,300 feet, or more, of dominantly dark Lower Jurassic shale cropping out in northern Veracruz, northern Puebla, and eastern Hidalgo

[1] Manuscript received, April 4, 1948. Published by permission of the director of the United States Geological Survey.

[2] Geologist, United States Geological Survey.

[3] Geologist, Petróleos Mexicanos.

in the mountains bordering the Huasteca area. The formation includes some interbeds of sandstone and conglomerate and a few lenses of limestone. The type section is designated as the nearly continuous exposures along the Río Vinasco south of Huayacocotla between Rancho Calera on the west and the river crossing leading to Rancho Bada on the east. This section is selected as the type because of relative accessibility, fairly good exposures, and its previous description by Burckhardt.[4] It appears to be much more complete than the Lower Jurassic section near Huauchinango, which is now accessible by car. Huayacocotla can be reached by car in about 4 hours from Tulancingo. The highest outcrops of the Lias near Rancho Calera can be reached by trail from Huayacocotla in about 1½ hours.

The term Potrero shale was proposed by Böse[5] for the same marine Lower Jurassic rocks in question, probably after Rancho Potrero Seco, which is a small farm southeast of Huayacocotla near the Río Vinasco. The name apparently was overlooked by everyone until recently[6] and was applied to a Lower Cretaceous formation in eastern Sonora.[7] After consultation with the geologists of the Instituto Geológico and Petróleos Mexicanos, it was decided to abandon the term Potrero shale in favor of Huayacocotla formation because the latter is a much more appropriate and permanent geographic designation and the former has never acquired usage. The name San Bartolo formation, proposed by W. R. Fehr and E. G. Bonnard in an unpublished manuscript prepared for the Mexican Eagle Oil Company, was not used because San Bartolo is rather inaccessible.

Stratigraphic and lithologic features.—The Huayacocotla formation exposed along the Río Vinasco near Huayacocotla, Veracruz, consists mostly of dark gray, greenish gray to nearly black, moderately hard claystone and siltstone at least 1,300 feet thick. Many beds are highly calcareous, but some are only slightly calcareous. Some of the siltstone beds are thin- to medium-bedded and resemble limestones at a distance. These are interbedded, particularly near the top of the formation, with minor amounts of greenish gray to gray, fine-grained sandstone and quartzitic sandstone. Many of the beds are micaceous and pyritic. A 4-foot bed of moderately coarse conglomerate interbedded with dark gray claystone was noted in the Río Vinasco just above the junction with Arroyo Naranjo near the Cuesta del Viejo crossing.[8] This conglomerate consists of moderately rounded pebbles of gneiss, quartzite, chert, and granitic rocks ranging mostly from 1 to 3 inches in diameter. Many outcrops of the Lower Jurassic, especially near Rancho

[4] Carlos Burckhardt, "Étude synthétique sur le mésozoique méxicain," *Abh. Schweizer. Palaeont. Gesell.*, Bd. 49 (1930), pp. 12–20, table 2.

[5] Emil Böse, "Über Lias in Mexico," *Zeit. Deutsche Geol. Gesell.*, Bd. 50 (1898), p. 175.

[6] R. W. Imlay, "Jurassic Formations of Gulf Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 11 (1943), p. 1497.

[7] R. E. King, "Geological Reconnaissance in Northern Sierra Madre Occidental of Mexico," *Bull. Geol. Soc. America*, Vol. 50 (1939), p. 1660.

[8] See map in Burckhardt (1930), *op. cit.*, p. 10.

Calera, are somewhat metamorphosed but this condition seems to vary within short distances. The fossils are mostly limonitic external molds, but some are pyritic. Ammonites occur throughout most of the formation. Plants occur in the basal part in association with the ammonites and at the top where ammonites are lacking.

The Huayacocotla formation on the Río Pantepec near San Bartolo, Hidalgo, approximately halfway between Huayacocotla and Huauchinango, has been studied by W. R. Fehr and E. G. Bonnard for the Mexican Eagle Oil Company and by Edmundo Cepeda for Petróleos Mexicanos. According to them, the formation consists of at least 1,000 feet of medium gray to yellow schist, slate, limestone, and sandstone, and a few thin lenses of fine conglomerate. It appears to become sandier eastward. Some beds are dark gray, brown, or red. Locally, small coal seams occur in sandy schists. Metamorphism of the beds is ascribed to local intrusions of basalt and quartz porphyry. Both ammonites and plant fossils of Lower Jurassic age have been found.

Near Huauchinango, Puebla, the exposures of the Huayacocotla formation consist mainly of dark gray to black claystones and siltstones that weather yellowish to reddish. Some beds are greenish gray. Most beds are micaceous and phyllitic.

The base of the Huayacocotla formation has not been observed. It presumably rests on metamorphic rocks, as indicated by the nature of the pebbles comprising the conglomerates within the formation. The contact with the overlying redbeds is probably disconformable because near Huehuetla, Hidalgo, conglomerates in the lower part of the redbeds are reported to contain fragments of the underlying Lower Jurassic slates.[9] Also along the Río Vinasco, just west of Rancho Zopilote, the conglomeratic redbeds at the base of the Upper Jurassic contain pebbles of shale, sandstone, and quartzite derived from the Lower Jurassic.[10] Locally along the Río Vinasco the Huayacocotla formation is overlain directly by marine limestone of Upper Jurassic age.

Correlation.—The age of the Huayacocotla formation has been determined by Burckhardt[11] and Diaz Lozano[12] on the basis of both ammonites and plants as middle Lower Jurassic representing at least the Sinemurian and part of the Pliensbachian stages.

Origin.—Burckhardt[13] considered that the marine Lower Jurassic beds of the Huasteca area were formed near shore in a bay with defective circulation. Nearness to shore is indicated by the presence of well preserved terrestrial plants,

[9] W. R. Fehr and E. G. Bonnard, "Geologic Cross-Section through the Sierra Madre Oriental from Mecapalapa to Cueva Humada," unpublished report prepared for the Mexican Eagle Oil Company.

[10] Burckhardt, *op. cit.*, (1930), p. 92.

[11] Burckhardt, *op. cit.* (1930), pp. 12–23.

[12] E. Diaz Lozano, "Descripción de unas plantas liásicas de Huayacocotla, Veracruz, y algunas plantas de la flora liásica de Huauchinango, Puebla," *Bol. Inst. Geol. Mexico*, Núm. 24 (1916).

[13] Burckhardt, *op. cit.* (1930), pp. 20–23.

sandstones with bivalves, and some conglomerates. Defective circulation is indicated by the bituminous character of the shale, the abundance of pyrite, and the abundance of ammonites compared with pelecypods. It is supposed that the bay opened seaward toward the east and that the conglomerates and sandstones were derived from the west or southwest, but the opposite may be true.

HUIZACHAL FORMATION

Definition.—The Huizachal (pronounced Wīź-a-chal) formation is herein formally defined as the 1,400 feet, or less, of redbeds directly underlying the normal marine Upper Jurassic in eastern and northern Mexico, overlying marine Lower Jurassic in the Huasteca area of Veracruz, Puebla, and Hidalgo, and overlying Paleozic or probable pre-Cambrian rocks at other places (Fig. 1). Its contact with the Lower Jurassic appears to be an erosional unconformity. Its contact with the overlying limestones of Oxfordian or Kimmeridgian age is an angular unconformity at several places and is clearly erosional at most places. The type section is designated as the southwest side of the Huizachal Valley near the head of Arroyo Juan Capitan, approximately 20 kilometers south-southwest of Victoria, Tamaulipas. This section is selected because the exposures are excellent and can be reached by car from Victoria on an all-weather road in approximately 1½ hours. From the viewpoint of bracketing the redbeds within the Jurassic, the thick section near Huehuetla, Hidalgo, would be preferable as the type, but it can now be reached only with pack animals. The name Huizachal formation was originally proposed by P. A. Robertson in 1925 in a report prepared for the Mexican Gulf Oil Company on the Sierra Madre west of Victoria, Tamaulipas.

Stratigraphic and lithologic features.—The Huizachal formation consists mostly of somewhat calcareous, medium to light red claystone, siltstone, fine-grained sandstone, quartzitic sandstone, and conglomerate and ranges from a few feet to more than 1,000 feet in thickness. The most common lithologic type is a medium red slightly sandy siltstone. Some of the sandy and shaly beds are green, gray, purple, brown, or yellowish red. A basal conglomerate ranging from 10 to 165 feet thick characterizes the formation, but conglomerates may occur in any part of the formation. In the mountains bordering the Huasteca area the conglomerates and associated quartzitic sandstones in the lower part of the formation are characteristically greenish gray to green but locally become reddish laterally or vertically within a few feet. Similar greenish conglomeratic beds have been observed in La Presa Canyon northwest of Victoria and in the Sierra de Catorce. The green and gray colors are largely inherited from schist, gneiss, and various coarse-grained intrusive rocks, whose fragments compose the bulk of the conglomerates, but are probably in part a result of the weathering of pyroxene and amphibole.

An interesting lithologic type in the Huizachal formation is red lava resembling siltstone. Dark red lavas difficultly separable in the field from associated red sandstone and shale occur in the Villa Juarez uplift west of Torreon, eastern

FIG. 1.—Jurassic salt and redbed localities in Mexico and Central America.

Durango.[14] In the Teziutlán area of central Veracruz and eastern Puebla the Huizachal formation contains some hard beds of red lava that are difficult to differentiate from associated red siltstone without examination under a petrographic microscope. Possibly lavas occur elsewhere in the formation but have not been recognized because of failure to make thin sections.

Limestone has been reported in the upper part of the redbed sequence in the San Pedro Valley near Almanza in central Veracruz,[15] and in the Sierra de Catorce in northern San Luis Potosí.[16] The limestone in question near Catorce is interbedded with gray calcareous shale about 100 feet thick that grades upward into thick-bedded limestone typical of the Zuloaga limestone and overlies red sandstone and siltstone typical of the Huizachal formation. The writers concluded after field examination that the limestone and gray shale belong lithologically and stratigraphically with the Zuloaga limestone rather than with the redbeds. This suggests that the reported occurrence of limestone in the redbeds near Almanza should likewise be reëxamined.

As the local stratigraphic features of the Huizachal formation have been discussed in fairly recent publications,[17] only new information concerning several areas is presented in subsequent paragraphs.

The type section on the southwest side of Huizachal Valley about 20 kilometers south-southwest of Victoria, as measured by M. B. Schmittou, from top to bottom is as follows.

	Thickness (Feet)
Conglomerate, red, poorly sorted. Pebbles are angular, range from ½ inch to 5 inches in diameter, and consist of red sandstone and shale and various igneous and metamorphic rocks	34
Sandstone, medium- to coarse-grained, well bedded, red	20
Shale, sandy, thin-bedded, red	25
Conglomerate as above but coarser, some boulders as much as 8 inches in diameter	30
Sandstone, coarse-grained, red	25
Shale, sandy, red	15
Sandstone, coarse-grained, thin-bedded, red	15
Sandstone, thin-bedded, red, alternating with red shale	20
Sandstone, very coarse-grained, red	15
Conglomerate, red	8
Shale and sandy shale, a few beds of red, fine-grained sandstone, rests on metamorphic rocks	170
Total thickness	377

The Huizachal formation may be an erosional remnant in the Huayacocotla area on the north side of the Río Vinasco just west of Rancho Zopilote northeast of Rancho Calera, where approximately 100 feet of reddish conglomerate occurs at the base of the marine Upper Jurassic limestone.[18] According to Burckhardt,

[14] L. B. Kellum, "Geology of the Mountains West of the Laguna District," *Bull. Geol. Soc America*, Vol. 47 (1936), p. 1062.

[15] Hans Jenny, unpublished report prepared for the Mexican Eagle Oil Company.

[16] C. L. Baker, "General Geology of the Catorce Mining District," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 66 (1922), p. 44.

[17] Imlay, *op. cit.* (1943), pp. 1475–79, 1504–11.
F. K. G. Müllerried, "Geología del Estado de Nuevo León," *Nuevo León Univ. Anales Inst. Inves. Cient.*, Tomo 1, No. 2 (1946), pp. 52–54.

[18] Burckhardt, *op. cit.* (1930), p. 92.

FIG. 1.—Jurassic salt and redbed localities in Mexico and Central America.

the conglomerate consists of pebbles of sandy shale and quartzite identical with rock types in the underlying Lower Jurassic and are in a matrix of red shale and sandstone. Elsewhere along the Río Vinasco below Rancho Calera the Upper Jurassic limestone rests directly on Lower Jurassic beds without an intervening red conglomeratic unit, according to observations by the writers. Burckhardt[19] considered that the conglomerate represented the basal part of the marine Upper Jurassic, but the presence of similar conglomerates in a thick redbed sequence a little farther south near Huehuetla suggests that the Huizachal formation may once have been well developed in the Huayacocotla area.

The red Huizachal formation crops out extensively along the Pantepec River at Huehuetla and westward toward San Bartolo, Hidalgo. According to Fehr and Bonnard,[20] the redbeds have their maximum development near Huehuetla but thin westward considerably and are locally absent within their area of outcrop. The description by Fehr and Bonnard may be summarized, from top to bottom, as follows.

	Thickness (Feet)
Marls mainly [equals calcareous siltstone and claystone of American geologists], red to violet, contain much mica and nests of malachite, weather splintery, lower part distinctly bedded, upper part massive and slaty	655
Marls, sandstones, and conglomerates, transitional into adjoining members	82
Quartzites, arkoses, conglomerates, and coarse, thick-bedded sandstone, white to light grayish green, lower part weathers gray, upper part weathers red; mica and pyrite common; conglomerate contains fragments of underlying Lower Jurassic rocks	655
Total thickness	1,392

Redbeds of the Huizachal formation are extensive in the mountainous Teziutlán area of central Veracruz and northern Puebla from Zacapoaxtla on the west to Almanza on the east. They consist mostly of light to medium red claystone, siltstone, sandstone, and conglomerate that are in part calcareous. Some of the beds, particularly in the lower part of the formation, are green or gray. Reddish lavas are interbedded with the sediments but are difficult to recognize excepting by microscopic examination of thin sections. Limestone was noted by Jenny[21] near the top of the redbeds in the San Pedro Valley near Almanza. Beds of conglomerate composed mostly of pebbles of intrusive igneous rocks characterize the lower part of the formation but may occur throughout the formation and are particularly common on the east slope of Sierra Chignahutla west of Teziutlán. Jenny reports that the upper part of the formation contains many plant fragments and that unidentifiable ammonites were found at one place, which he

[19] Burckhardt, *ibid.*

[20] W. R. Fehr and E. G. Bonnard, "Geologic Cross-Section through the Sierra Madre Oriental from Mecapalapa to Cueva Humade," unpublished report prepared for the Mexican Eagle Oil Company.

[21] Hans Jenny, "Geological Reconnaissance in the Area Northwest, North and Northeast of Teziutlán, Puebla, and Veracruz," unpublished manuscript prepared for the Mexican Eagle Oil Company.

does not specify. The thickness of the formation is probably at least 1,000 feet.

The Huizachal formation rests on rocks of various ages ranging from Lower Jurassic to probable pre-Cambrian. It rests on Lower Jurassic in the mountains west of the Huasteca area; on Permian in La Presa Canyon northwest of Victoria; on moderately metamorphosed rocks that are probably younger than pre-Cambrian in the Sierra de Catorce; and on a complex of gneisses, schists, and various kinds of coarsely crystalline intrusive rocks in the Teziutlán area of central Veracruz, at many localities in southwestern Tamaulipas and southern Nuevo León, and in the subsurface of the Tampico area. The contact of the Huizachal formation with the Lower Jurassic strata is disconformable because near Huehuetla, Hidalgo, conglomerates in the lower part of the formation contain fragments of the underlying Lower Jurassic slates and phyllites.[22] Also along the Río Vinasco just west of Rancho Zopilote the conglomeratic redbeds at the base of the Upper Jurassic contain pebbles of shale, sandstone, and quartzite derived from the Lower Jurassic rocks.[23] The contact of the Huizachal formation with rocks older than Jurassic probably represents an angular discordance, although Cañón de Catorce just west of Catorce is the only locality visited by the writers where this relationship is clearly shown.

The Huizachal formation is overlain throughout most of its known extent by marine Upper Jurassic rocks. At most places the overlying rocks are Oxfordian limestones.[24] However, near Tampico the overlying rocks are Kimmeridgian in age,[25] and near Miquihuana in southwestern Tamaulipas they are early Lower Cretaceous (Valanginian) in age.[26] The relationships near Tampico have been explained as an overlap of Kimmeridgian beds along the eastern margin of an Upper Jurassic landmass,[27] and those near Miquihuana have been demonstrated by Burckhardt[28] to be a result of uplift and erosion in late Upper Jurassic and earliest Cretaceous time. The contact of the red Huizachal formation with the Oxfordian Zuloaga limestone is clearly unconformable because the latter is marked at many places by a basal conglomerate whose pebbles are derived partly from the underlying redbeds[29] and because in the Aramberri area the Zuloaga

[22] Fehr and Bonnard, *op. cit.*

[23] Burckhardt, *op. cit.* (1930), p. 92.

[24] Imlay, *op. cit.* (1943), pp. 1482–83, 1506.

[25] Burckhardt, *op. cit.* (1930), pp. 95, 96.
Muir, *op. cit.* (1936), pp. 15, 16, 33, 35.
Imlay, *op. cit.* (1943), pp. 1506, 1510, 1512, 1513.

[26] R. W. Imlay, "Lower Neocomian Fossils from the Miquihuana Region, Mexico," *Jour. Paleon.*, Vol. 11, No. 7 (1937), pp. 554–57.

[27] Imlay, *op. cit.* (1943), p. 1510.

[28] Burckhardt, *op. cit.* (1930), pp. 86–90.
Imlay, *op. cit.* (1937), pp. 555, 557.
R. W. Imlay, "Cretaceous Formations of Central America and Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 8 (1944), p. 1143.

[29] Imlay, *op. cit.* (1943), pp. 1482, 1483.

limestone overlaps the redbeds onto mica schists.[30] Furthermore, in at least two localities the contact is an angular unconformity. One of these is excellently shown in Cañón La Presa northwest of Victoria, where Heim[31] noted an angular discordance of 30°.[32] Another has been reported by Hans Jenny and Edmundo Cepeda,[33] who have noted that in the northern part of the Teziutlán area of central Veracruz and northern Puebla strongly folded redbeds at several places are overlain sharply by gently dipping marine Upper Jurassic limestone, whose basal beds contain fragments derived from the underlying redbeds as well as from gneiss, schist, and granitic rocks. In fact, it appears that folding and subsequent erosion have locally brought gneiss and schist in direct contact with the Upper Jurassic limestone.

Correlation.—The redbeds here included in the Huizachal formation have been tentatively assigned by various writers to ages ranging from Permian to Jurassic.[34] However, in the mountains bordering the Huasteca area the Huizachal formation may be bracketed within the Jurassic because it overlies the Lower Jurassic and underlies the upper Oxfordian or Kimmeridgian limestone of the Upper Jurassic. As the formation has not furnished identifiable fossils, its exact age is unknown, but disconformities at both its top and bottom indicate that it does not represent the entire time between the Lower Jurassic and the upper Oxfordian. On the contrary, various considerations have suggested to Imlay[35] that its age is probably only lower Oxfordian (Divesian) because (1) the older stages of the Upper and Middle Jurassic in southern Mexico are well represented by marine faunas or by coal and plant-bearing beds, (2) the redbeds and associated salt in southern Mexico are associated with beds of Upper Jurassic age, and (3) aridity over large parts of both North and South America appears to have been excessive during the lower Oxfordian.[36] Correlation of the redbeds comprising the Huizachal formation with the Eagle Mills formation of the southern United States has been made by Imlay[37] on the basis of similar lithologic characteristics, stratigraphic position, and areal distribution. The validity of this corre-

[30] F. K. G. Müllerried, "Geologiá del Estado de Nuevo León," *Nuevo León Univ. Anales Inst. Inves. Cient.*, Tomo 1, No. 2 (1946), p. 54.

[31] Arnold Heim, "The Front Ranges of Sierra Madre Oriental, Mexico, from Ciudad Victoria to Tamazunchale," *Ecologae Geol. Helvetiae*, Vol. 33, No. 2 (1940), p. 318.

[32] This locality is now easily accessible by passenger car from Victoria to a point approximately 2 miles west of Peregrina.

[33] Unpublished reports in the files of Petróleos Mexicanos.

[34] Heim, *op. cit.* (1940), p. 318.
Müllerried, *op. cit.* (1946), pp. 52, 70.

[35] Imlay, *op. cit.* (1943), pp. 1508–10.

[36] G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 193, 338–40.
A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *ibid., Prof. Paper 183* (1936), pp. 6–8, 45, 46, 54, 58, Fig. 16.
L. G. Weeks, "Paleogeography of South America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31 (1947), p. 1211.

[37] Imlay, *op. cit.* (1943), p. 1437, 1438, 1510.

lation has been emphasized by the field work on which this paper is based. Geologists familiar with the Eagle Mills formation would see many points of resemblance between it and the Huizachal formation.

Association of the redbeds and salt in the Isthmus of Tehuantepec appears to be similar to the association of the redbeds and salt of the Eagle Mills formation in the southern United States and probably has a similar origin and age relationship. It may be that the main mass of salt is correlative with the time represented by the disconformity between the Huizachal formation and overlying upper Oxfordian limestone in eastern and northern Mexico. Possibly the local strong folding of the Huizachal formation prior to the deposition of the Oxfordian limestone, as in the Teziutlán area, signifies uplift of the borders of the Gulf of Mexico, producing thereby an enclosed, or nearly enclosed, sea and perhaps eventually the deposition of anhydrite and salt. If the redbeds themselves were deposited in waters highly saturated with salt, then an uplift of the bordering landmasses may have acted as a trigger releasing the salt quickly over a large area.

The sequence of events established for the Jurassic of Mexico may be useful in interpreting Jurassic history in the Gulf region of the United States and should be considered in connection with the age of the redbeds and salt underlying the Smackover formation. Recently, Hazzard, Spooner, and Blanpied[38] published an excellent summary of information pertaining to the beds below the Smackover limestone. They present rather convincing evidence that most of the redbeds, including the type section of the Eagle Mills formation, underlie the main sequence of salt and anhydrite, instead of grading laterally into it, and may usefully be considered a separate formation.[39] They show that some higher redbeds and associated conglomerates overlying the salt mass and underlying the Smackover limestone transgress all older rocks onto the Paleozoic, are invariably associated with the Smackover limestone, and probably represent the basal deposits of the advancing Smackover sea.[40] They propose to call these 150 feet or less of gravelly redbeds the Norphlet formation, the underlying 600–1,300 feet of salt the Louann salt (Eagle Mills salt of Imlay), and the underlying 100–200 feet of anhydrite, redbeds, and gravel the Werner formation (Louann tongue of Eagle Mills of previous publications). From the data presented they infer that the Norphlet formation is separated from the Louann salt by a regional unconformity, that the Werner formation is separated from the Eagle Mills formation by a regional unconformity, that the Eagle Mills formation is older than the Morehouse formation, which contains late Paleozoic fossils, and that all the evaporite

[38] Roy T. Hazzard, W. C. Spooner, and B. W. Blanpied, "Notes on the Stratigraphy of the Formations Which Underlie the Smackover Limestone in South Arkansas, Northeast Texas, and North Louisiana," *Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi, and Alabama*, Vol. 2 (Shreveport Geological Society, 1946), pp. 483–503; 3 cross sections, 3 pls.

[39] Hazzard, Spooner, and Blanpied, *ibid.*, pp. 485, section cc′.

[40] Hazzard, Spooner, and Blanpied, *ibid.*, pp. 488–96.

sequence to the top of the Louann salt is more probably Permian than Jurassic. They consider the Eagle Mills formation older than the Morehouse formation because the Union Producing Company's Tensas Delta No. A-1 in Morehouse Parish, Louisiana, penetrated 1,190 feet of dark shales and limestones of the Morehouse formation directly beneath the Werner formation of Hazzard *et al.*, whereas the Union Producing Company's Crossett No. E-1, 19 miles northeast in Arkansas, penetrated 4,652 feet of redbeds of the Eagle Mills formation directly below the Werner formation. Neither the base of the Morehouse nor of the Eagle Mills was reached. They thought it improbable that two such distinct facies could grade laterally into each other within 19 miles, or that structural conditions existed that would permit the Morehouse shale to pass under the Eagle Mills formation. Structurally it would appear much simpler if the Eagle Mills passed beneath the Morehouse shale.

However, on the basis of the new information concerning the Jurassic of Mexico, as discussed herein, other interpretations of the data concerning pre-Smackover beds than those made by Hazzard, Spooner, and Blanpied may be considered. First, the lithologic and stratigraphic similarity of the Huizachal formation to the Eagle Mills formation and the evidence of strong folding and erosion after Huizachal time suggests the possibility of pronounced local faulting or folding of the Eagle Mills formation before deposition of the evaporite sequence and might explain the puzzling relationships between the Eagle Mills formation and Morehouse shale. Second, a thick mass of salt in southern Mexico appears to occupy the same stratigraphic position as the evaporite sequence above the Eagle Mills formation and may be related genetically to the unconformity noted at the top of the Huizachal formation. Third, the thin conglomeratic redbeds at the base of the Zuloaga limestone in Mexico are similar lithologically, stratigraphically, and in thickness to the conglomeratic sandstones (Norphlet formation of Hazzard *et al.*) at the base of the Smackover formations in the southern United States and likewise transgress redbeds onto late Paleozoic sedimentary rocks, or still older metamorphosed igneous rocks. If these similarities reflect a common origin and history, then the unconformity at the base of the Norphlet formation of Hazzard would represent only a minor part of Jurassic time and would not prove the presence of an unconformity at the same stratigraphic position in areas of salt deposition.

Origin.—Deposition of the Huizachal formation in a large body of water is suggested by its generally even bedding, the presence of a basal conglomerate, the scarcity of cross bedding, the intimate association of red lavas with redbeds locally, and by association of redbeds with salt and anhydrite in parts of southern Mexico. The lack of fossils, excepting for a few plant stems and a fragmentary ammonite noted by Hans Jenny, may be explained by deposition in highly saline or perhaps brackish waters, and does not necessarily mean continental conditions.[41] Deposition in saline rather than brackish waters is favored by the uniform

[41] Imlay, *op. cit.* (1943), p. 1479.

character of the formation throughout its extent in northern, eastern, and southern Mexico. If the formation was of brackish-water origin, some changes suggesting marine conditions should be observed in that area. The conglomerates in the formation in the Sierra Madre Oriental were probably derived from local uplifts, as were similar conglomerates in the Lower Jurassic beds of the Huasteca area.

The considerable thickness of the formation at some places, its marked variability in thickness within short distances, and its absence locally in its area of outcrops may be explained (1) by deposition on an uneven surface, (2) by deposition on a surface that was undergoing differential movement, or (3) by folding and erosion after deposition. The first possibility is suggested by the variation in thickness of the basal conglomerate from 10 to 165 feet and by the presence of boulders up to 8 inches in diameter. The second possibility is indicated by the presence of some red sandstone and shale pebbles in the conglomerates within the redbeds, as near Huizachal, Tamaulipas. The third possibility can be verified on the outcrops west of Victoria, Tamaulipas, and in the northern part of the Teziutlán area of central Veracruz, where steeply dipping redbeds are overlain by gently dipping Upper Jurassic limestone (Zuloaga limestone and Tamán formation) that basally contain pebbles derived from the redbeds.

The characteristics of the Huizachal formation suggest that it formed as a transgressive deposit along the western margin of the Gulf of Mexico during a time of great aridity. The transgression was probably started by minor tectonic movements at, or near the end of, the Callovian that widened the Gulf and locally elevated small positive areas along its margin. These positive areas apparently continued to rise during the deposition of the Huizachal formation and shed pebbles of schist, gneiss, various coarse-grained intrusive rocks, and some red sandstone and shale into the surrounding basins. At the close of the redbed deposition occurred general uplift, local strong folding, and considerable erosion, which in places completely removed the redbeds. This was followed in upper Oxfordian or, locally, Kimmeridgian time, by a marine transgression that reworked the surface of the redbeds.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1762-1807, 12 FIGS., 3 TABLES

BURIED TOPOGRAPHY, INITIAL STRUCTURES, AND SEDIMENTATION IN SANTA ROSALÍA AREA, BAJA CALIFORNIA, MEXICO[1]

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ABSTRACT

The geologic history of the west side of the Gulf of California is particularly well recorded near the copper-mining town of Santa Rosalía, Baja California, Mexico. During the Miocene a thick accumulation of volcanic rocks (Comondú volcanics), grading westward into terrestrial sediments, was derived from the present site of the Gulf. These rocks were gently tilted westward over most of the peninsula, perhaps in the form of a tilted fault block, but were locally strongly deformed by faulting near the Gulf. Great subsidence of the former highlands on the site of the Gulf occurred, perhaps as a result of downfaulting. When the first engulfment by the sea occurred near Santa Rosalía, starting probably in early Pliocene time, the topography of the Comondú surface was still in a stage of late youth or early maturity, having a local relief of 450 meters. As a result there existed a rugged shoreline with an irregular topography, characterized by headlands, bays, submarine hills and ridges, and islands. The deposition of Pliocene and Pleistocene sediments over this initial topography resulted in prominent initial structures. Anticlinal structures were produced over buried hills, and synclinal structures were formed over pre-existing valleys. The lowest deposits, particularly a peculiar basal marine limestone, show the highest initial dips, commonly as great as 30°. The higher beds show successively gentler dips as the sediments wedged out against the hills and filled in the basins. The initial structures have been modified by tilting and normal faulting occurring at various times. The conditions of sedimentation and the origin of the initial structures are discussed, and the literature is reviewed concerning initial structures described in other regions.

INTRODUCTION

The coastal area near Santa Rosalía, Baja California, Mexico, provides an exceptionally clear picture of the geologic events leading up to and resulting from the development of the Gulf of California. In this area the Gulf once extended 6–10 kilometers farther inland than at present, and the deposits formed along its western border since early Pliocene time are well exposed. Various facies changes record the effects of a rugged shoreline on depositional conditions. Of particular interest are structures produced in the Pliocene sediments as a result of the inundation of an irregular topography by the sea. The writer has seen no other area in which the effects of original topography on subsequent structures are shown so well. The area has been so extensively explored by mine workings

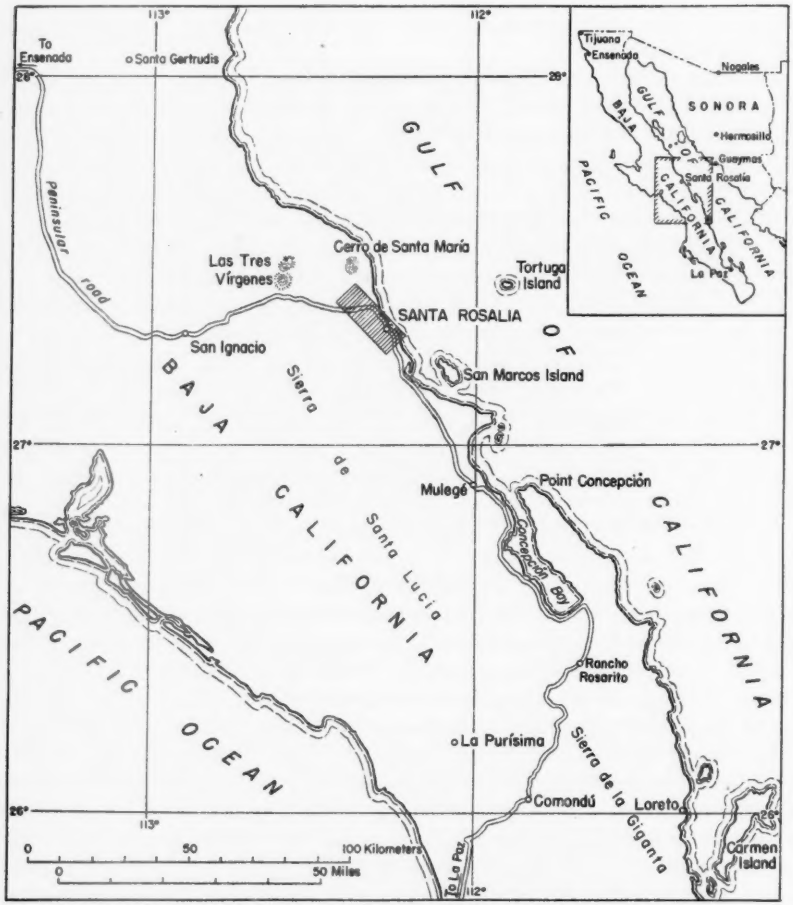
[1] Manuscript received, May 3, 1948. Published by permission of the director of the United States Geological Survey.

[2] Geologist, United States Geological Survey. This paper results from investigations by the U. S. Geological Survey in cooperation with the Direccion General de Minas y Petróleo, the Instituto de Geología, and the Comité Directivo para la Investigación de los Recursos Minerales de México. These studies form part of the program for cooperation with the American Republics sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation of the United States Department of State. The field work in the Lucifer district was done in collaboration with Mario Veytia, and in the Boleo district with Victor S. Rocha. Kenneth Segerstrom of the United States Geological Survey made a topographic map of the Boleo district. Helpful advice was given by Parker D. Trask, who examined the Lucifer district for the Geological Survey in 1943; and by J. V. N. Door, 2d, and William G. Kane, who visited the area with the writer. Numerous fossils were determined by H. E. Vokes, and some echinoids by C. Wythe Cooke. Carl Fries, Jr., gave helpful suggestions and reviewed the manuscript. Valuable criticisms have also been given by Miss Marjorie Hooker. The writer is grateful for the generous hospitality of P. Mahieux, F. L. García Quintanilla, and A. Nopper of the Boleo Company.

and drill holes that an unusually complete three-dimensional picture of the geology may be obtained.

The data in this paper result from strategic-mineral studies, occupying about 7 months of field work during parts of 1943 to 1946, of the Boleo copper district, centered at Santa Rosalía, and the Lucifer manganese district, adjoining it on the northwest, as well as of several other manganese deposits scattered at various points along the east side of Baja California. A general reconnaissance was made of the area between San Ignacio, on the northwest, and Rancho Rosarito, south of Concepción Bay, on the southeast, including visits to Las Tres Vírgenes, Cerro de Santa María, San Marcos Island, and the Point Concepción peninsula (see Fig. 1). The Boleo and Lucifer districts were mapped in detail, on scales of 1:10,000 and 1:15,000, respectively, the two adjoining areas totaling about 165 square kilometers. The economic and general geologic results of these studies are given in separate reports to be published by the United States Geological Survey. The purpose of the present paper is to describe exceptional Pliocene and Pleistocene structures and sedimentation resulting from the burial of a topography of high relief on the sea floor, and to point out the more important conclusions relating to the origin and history of the Gulf of California.

The previous literature on Baja California is reviewed in greater detail in the writer's other reports. The papers of greatest value bearing on the region under discussion are the reconnaissance reports of Gabb (1868); Lindgren (1889, 1890, 1891); Heim (1915, 1916, 1921, 1922), whose stratigraphic work near La Purísima and Comondú (presented most fully in the 1922 paper) was particularly useful; Darton (1921), who presents 21 sections across the peninsula; the Marland Oil Company (1924), whose report includes a geologic map of Baja California; the voluminous geographic study by Nelson (1921); and the studies of the Boleo copper district by Touwaide (1930) and Locke (1935). Older papers on the Boleo district by Fuchs (1886a, 1886b), Saladin (1892), and Krusch (1899) are mainly of historic interest. Other reports touching on the Santa Rosalía or near-by areas include those of Grewingk (1848), Emmons and Merrill (1894), who chiefly discuss the northern part of the peninsula, Merrill (1897), Bustamente (1921), Wilhelm (1921), Gálvez *et al.* (1922), Hirschi (1926), Hirschi and De Quervain (1927–1933), Hisazumi (1930), Flores (1931), Beal (1945), and Mariaca Bilbao (1945). Fossils collected from the Santa Rosalía area are discussed by Arnold (1906), Aguilera (1907), Hertlein (1925, 1931), and Hertlein and Jordan (1927). Papers concerning the Gulf of California and its islands include those by Muñoz Lumbier (1919), Paredes (1920), Johnston (1924), Hanna (1927), Hanna and Hertlein (1927), Revelle (1939, 1943), Sverdrup (1940), Shepard (1941), Osorio Tafall (1943, 1946), and Durham (1947). A paper by C. A. Anderson on the islands in the Gulf of California, of which an abstract has been published (1941), and a paper by J. W. Durham on the paleontology are in process of publication at the time of this writing. Several other reports are referred to in various parts of the text and listed in the bibliography.



INDEX MAP OF PART OF BAJA CALIFORNIA, MEXICO, SHOWING AREA MAPPED NEAR SANTA ROSALIA, AND OTHER LOCALITIES REFERRED TO IN TEXT

FIG. 1

Practically all the previous geologic work done, at least in the southern half of Baja California, has been of a reconnaissance nature, and as far as the writer is aware the Santa Rosalía area is perhaps the first of any size to have been mapped in considerable detail. Areas west of San Ignacio are said to have been mapped in detail in recent years by geologists for Petróleos Méxicanos, but it is not known whether the results will be published.

GEOGRAPHIC FEATURES OF BAJA CALIFORNIA AND GULF OF CALIFORNIA

Baja California is a long, narrow peninsula extending about S. 30° E. from the California state line, and is bordered by the Pacific Ocean on the southwest and the Gulf of California on the northeast (Fig. 1). The peninsula is nearly 1,200 kilometers long, and has an average width of about 100 kilometers, ranging from 50 kilometers, west of La Paz Bay, to 210 kilometers at the widest point, south of Sebastian Vizcaino Bay.

The peninsular divide, at least in the southern two-thirds of peninsula, is generally near the Gulf of California coast. Thus this part of the peninsula has an asymmetric cross section, consisting of a gentle westerly slope toward the Pacific, which in many places is bordered by a broad coastal plain, and a steep easterly slope into the Gulf of California, where at many places the shores are rugged and lack wide beaches or a coastal plain. The peninsula was early regarded as a westward-tilted block of the Sierra Nevada type, bordered on the east by a fault scarp (Gabb, 1868; Lindgren, 1889, pp. 194–96). This may be over-simplified, although it does seem to apply fairly well to the south-central part of the peninsula, where an eastern fault scarp is suggested by the steep gulf face of the Sierra de Santa Lucía and the Sierra de la Giganta, as pointed out by Johnston (1924, p. 952).

The principal range of the central part of the peninsula, from La Paz Bay northward to the vicinity of Santa Gertrudis, is composed mainly of Tertiary volcanic and sedimentary rocks, mantled here and there by more recent volcanic cones and flows. Two altitudes range commonly from 600 to 1,700 meters, culminating in the recent volcanic cones of Las Tres Vírgenes, northwest of Santa Rosalía, which attain an altitude of 1,997 meters. In the northern part of the peninsula the main range is the Sierra San Pedro Mártir, which reaches an elevation of 3,088 meters and consists largely of plutonic rocks. This is described by Woodford and Harriss (1938) as a well preserved fault block only slightly tilted westward, bordered on the east by a steep fault scarp and on the west by two or three fault scarps separated by steps. On the Pacific side of the peninsula, south of Sebastian Vizcaino Bay, is a separate, smaller, obliquely trending mountain range which terminates at the northwest in Cedros Island, and another small range lies farther south near Magdalena Bay. In the Cape region, south of La Paz, is a north-south granitic range attaining an altitude of 2,400 meters, which seems not to have the asymmetric structure of the ranges farther north.

The Gulf of California, sometimes called the Sea of Cortez, is a deep trough which parallels the peninsula of Baja California on the northeast. It averages about 160 kilometers in width, ranging from 90 kilometers near Tiburón Island to about 200 kilometers at the southeast end. Most of the Gulf south of Latitude 28° (the latitude of Guaymas, Sonora) has a depth ranging from 1,000 to 2,000 meters, increasing to more than 3,000 meters in the deepest parts (Osorio Tafall, 1946, bathymetric chart facing p. 110). The northern part of the Gulf is shallower. Shepard (1941) lists several indications of downfaulting in the Gulf, such as nar-

row steep-walled deeps cutting the central floor somewhat *en échelon*, bordered by terraces interpreted as due to step faults, and steep submarine escarpments bounding islands near the west side of the Gulf. There are forty or more islands in the Gulf having areas of 20–1,000 square kilometers, and about as many more islets and rocks (Johnston, 1924). Most of the islands on the Baja California side are merely separated remnants of the peninsula, but a notable exception is Tortuga Island, east of Santa Rosalía, which is a fairly recent volcano containing a perfect crater in its summit.

Much of Baja California is characterized by an extreme desert type of climate and vegetation, and the Gulf side is perhaps as dry as any part of North America. Owing mainly to insufficient water resources, the peninsula is very thinly populated. The most important towns south of Ensenada are La Paz, on the Gulf coast near the southern tip, and Santa Rosalía, situated about half-way down the Gulf coast, opposite Guaymas, Sonora. Santa Rosalía, a copper-mining town with a smelter and artificial harbor, established about 60 years ago by the French-owned Boleo Company, is near the center of the area with which this paper is principally concerned.

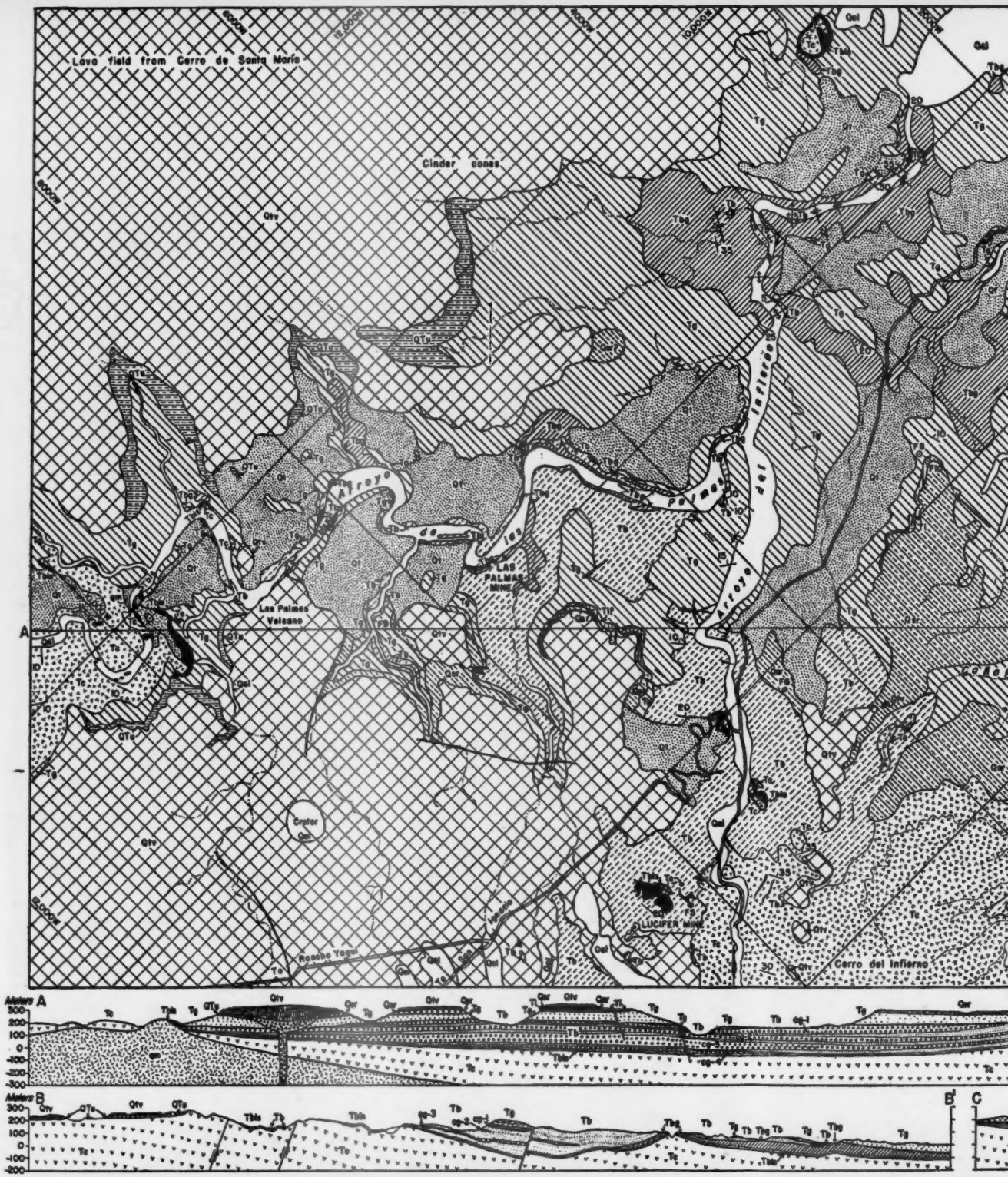
STRATIGRAPHIC COLUMN NEAR SANTA ROSALÍA, BAJA CALIFORNIA

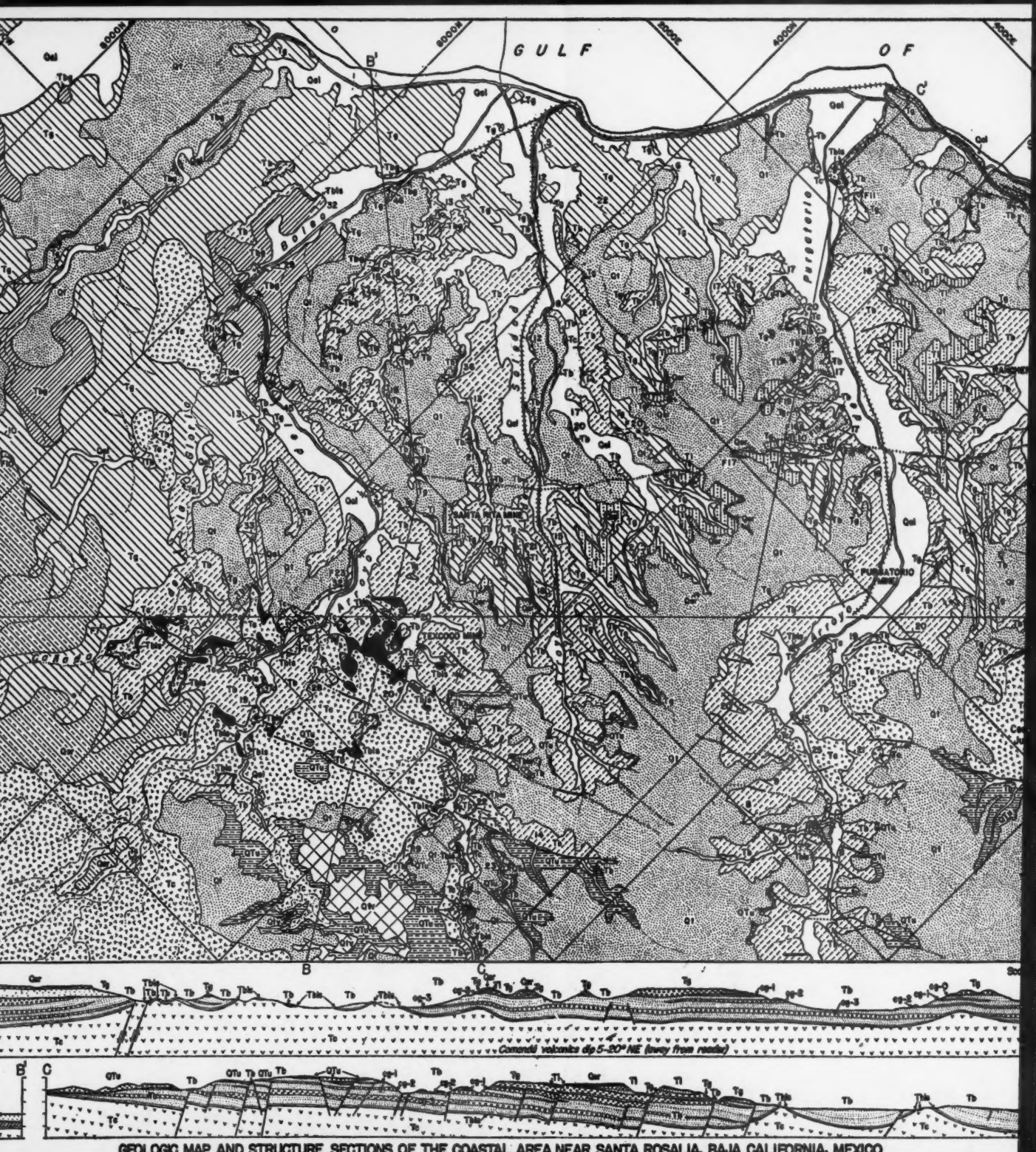
The stratigraphic column for the region is presented in Figure 2, and a geologic map and structure sections are given in Figure 3. The map is a generalized compilation on a smaller scale of the maps of the Boleo and Lucifer districts. The structure sections are controlled by drill holes and numerous mine workings which follow individual beds, so that the structure, particularly of the Pliocene beds, is shown in greater detail than would be possible from surface observations alone.[3] The formations are described in greater detail in the writer's other reports on the Boleo and Lucifer districts, and the larger-scale maps accompanying those reports show a greater number of lithologic subdivisions.

A plutonic basement, composed locally of quartz monzonite, is exposed only in a few very small scattered areas, as in Arroyo de las Palmas (left-hand edge of map and section *AA'*, Fig. 3).[4] Although granitic rocks are widespread north of Santa Gertrudis and south of La Paz, in the intervening area they are almost completely covered and are exposed only in a few small erosional windows. In this respect the small-scale geologic map of the Marland Oil Company (1924) is correct, whereas other geologic maps of Baja California which show large areas of granitic rocks in this region are incorrect. An Upper Cretaceous age was determined for plutonic rocks near Ensenada (Böse and Wittich, 1913, pp. 347–51;

[3] Approximately right-hand two-thirds of section *AA'* is controlled by nearly continuous mine workings supplemented by drill holes. Central third of section *BB'*, left-hand two-thirds of section *CC'*, and the right-hand two-thirds of section *DD'* are similarly controlled; remaining parts of sections are based on outcrops.

[4] It should be pointed out that there are no pre-granitic metamorphic rocks clinging to the plutonic core in Arroyo de las Palmas as was stated by Touwaide (1930, p. 119); the pink "quartzite" mentioned by him is a sandstone member of the Comondú volcanics, which rests depositionally on the plutonic rock.


Lava field from Cerro de Santa María
Cinder cones
Las Palmas Volcano
LAS PALMAS MINE
LUCIFER MINE
Cerro del Infierno
Rancho Yegui
Crater
Arroyo de las Palmas
Arroyo del Infierno
A
B
B'
C
Meters
300
200
100
0
-100
-200



GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE COASTAL AREA NEAR SANTA ROSALIA, BAJA CALIFORNIA, MEXICO

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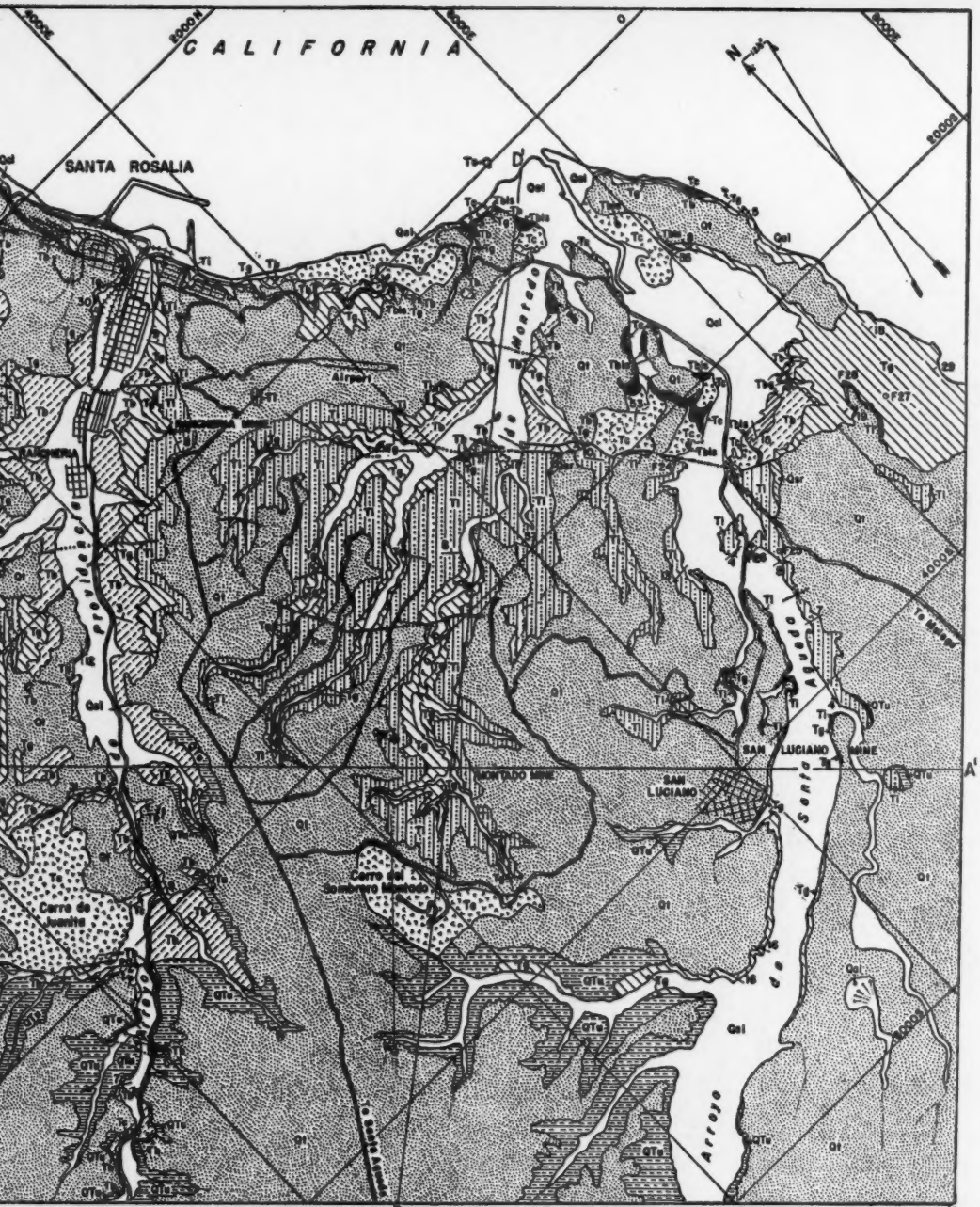


EXPLANATION

- Qal — Alluvium
- Qt — Terrace and gravel deposits
- Qtv — Tres Vírgenes volcanics
- Qsr — Santa Rosalía formation
- QTu — Undifferentiated post-Boleo beds
- Tl — Infierno formation
- Tg — Gloria formation
- Tb — Boleo formation (Tbg–gypsum; Tbls–limestone)
- Tc — Comondú volcanics
- gm — Quartz monzonite

Recent; Pleistocene; Mid. Plio. to Pleistocene; Upper Pliocene; Middle Pliocene; Lower Pliocene; Miocene — QUATERNARY; TERTIARY; Pre-Tertiary

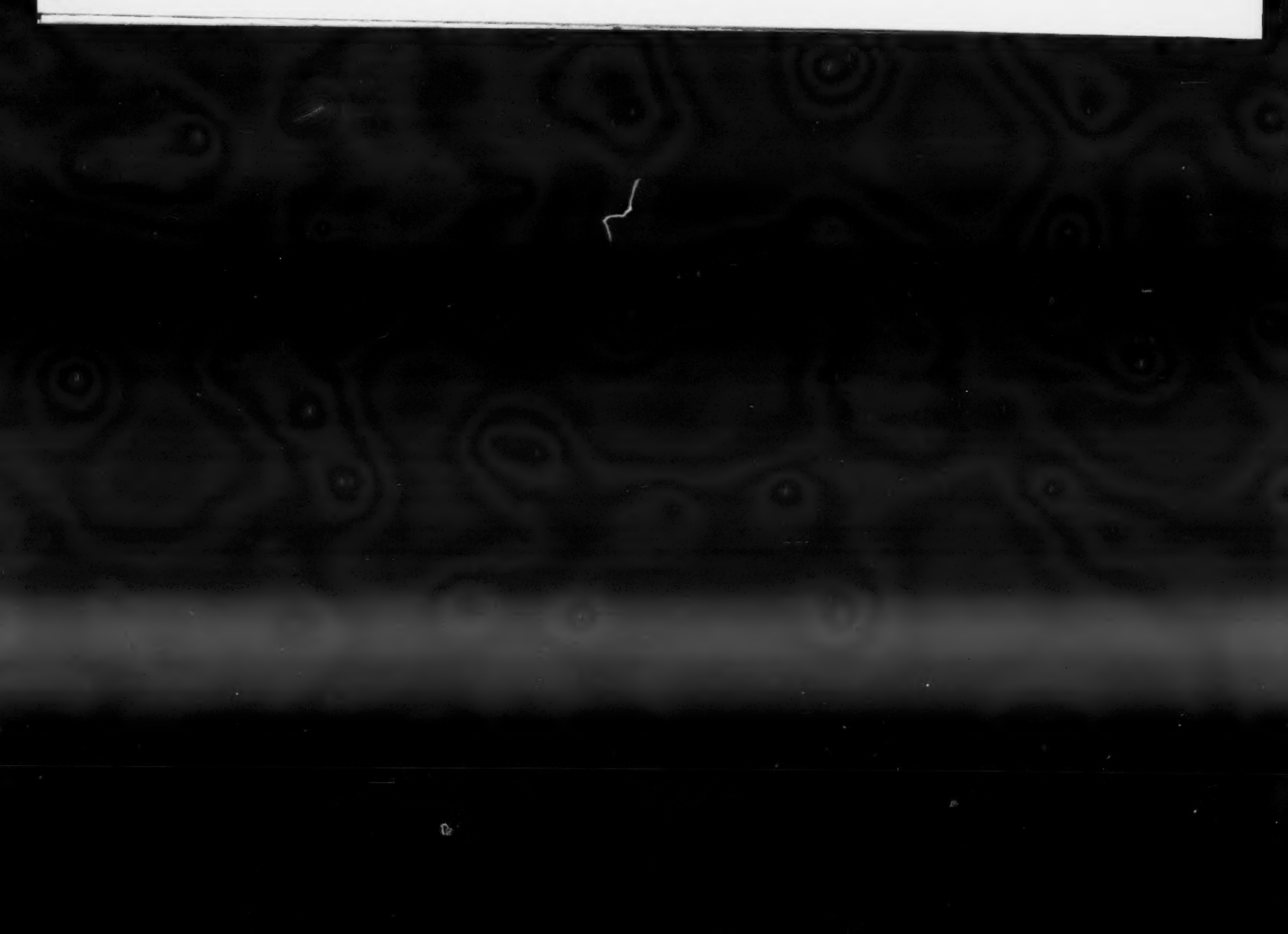
- Fault; dotted where concealed
- Contact
- 15 — Strike and dip of beds
- Axis of anticline
- Axis of syncline
- F12 — Fossil locality
- Road
- Railroad

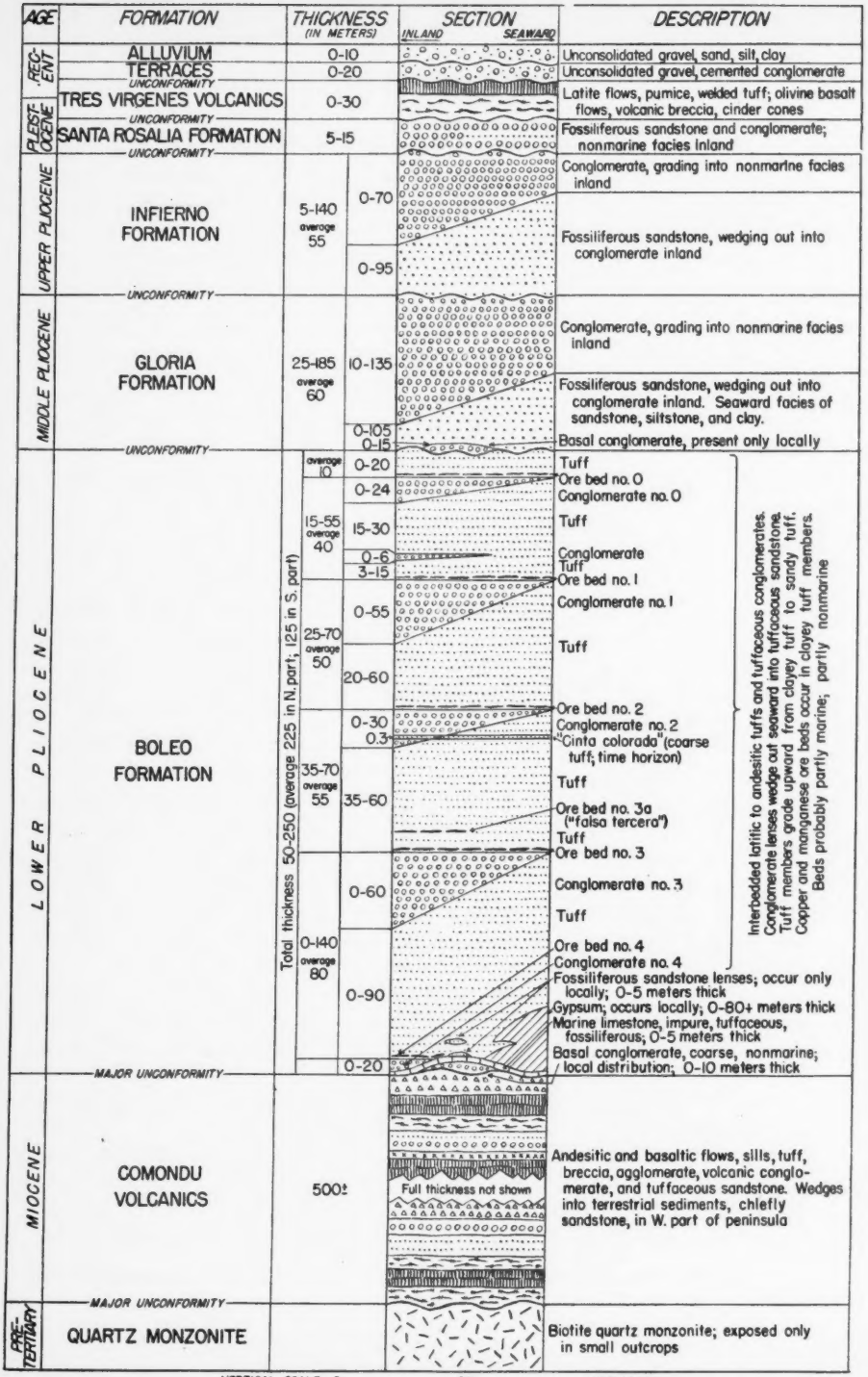
Coordinates are in meters; center is San Francisco shaft

IN SECTIONS:

"cg-1", "cg-2", etc. refer to numbered conglomerate members of Boleo formation. For lithologic details see stratigraphic column. Alluvium and terrace deposits omitted from sections. Vertical and horizontal scales the same

Prepared by Ivan F. Wilson, U. S. Geological Survey





STRATIGRAPHIC COLUMN IN THE VICINITY OF SANTA ROSALIA, BAJA CALIFORNIA

FIG. 2

Wittich, 1915; Woodford and Harriss, 1938, p. 1330; Woodford, 1940, p. 256), but there is no direct evidence for the age of the granitic rocks in the southern part of the peninsula. Darton (1921, p. 725) considered them pre-Cretaceous.

Cretaceous,[5] Eocene, Oligocene (?), and lower Miocene marine sediments were deposited on the west side of the peninsula of Baja California, but none reached the east coast in the vicinity of Santa Rosalía, although VanderHoof (1941) reports Oligocene remains from beds at San Carlos Bay, 80 kilometers northwest of Santa Rosalía.

The Miocene Comondú formation of Heim (1922, pp. 542–43) is represented mainly by a thick non-marine sequence of volcanic and pyroclastic rocks near Santa Rosalía, which wedge out into terrestrial sediments toward the west. These rocks make up the bulk of the main mountain range of the peninsula of Baja California, at least from the latitude of Santa Rosalía as far south as Comondú and Loreto.

The Pliocene beds may be divided into three formations separated by unconformities, which are assigned tentatively to the lower, middle, and upper Pliocene, respectively. These age assignments are based on numerous fossils examined by H. E. Vokes, who states that the large number of new species in the collections and the unknown ranges of many of the previously described species make precise age assignments difficult. He believes it certain that most of the collections are of Pliocene age, although their exact ages within that epoch must be considered tentative.

The writer proposes the name Boleo formation (named for the Boleo district) for the lower Pliocene succession of tuffs and conglomerates containing copper and manganese deposits, along with a basal marine limestone, gypsum, and fossiliferous sandstone. The name Gloria formation (named for Cañada de la Gloria) is proposed for the middle Pliocene beds, consisting of a thin basal conglomerate, highly fossiliferous marine sandstone, and overlying conglomerate, with a seaward facies of interbedded siltstone and clay. The name Infierno formation (named for Arroyo del Infierno) is proposed for the upper Pliocene beds, consisting of fossiliferous marine sandstone and conglomerate.

C. A. Anderson informs the writer (letter dated May 17, 1947) that he noted a similar three-fold division of the Pliocene beds on the islands studied by him in the Gulf of California. In a paper prepared for publication he has named these the San Marcos, Carmen, and Marquer formations, representing the lower, middle, and upper Pliocene, respectively. The San Marcos formation, named for San Marcos Island, is lithologically similar to the Boleo formation and appears to be of the same age. The Carmen and Marquer formations, named for localities on Carmen Island, are somewhat different lithologically from the formations at Santa Rosalía, but faunally appear to be equivalent to the Gloria and Infierno formations, respectively. Anderson suggests that his names be used for the

[5] A summary of the Cretaceous formations of Baja California is given by Anderson and Hanna (1935).

islands in the Gulf and the writer's names for the Santa Rosalía area.

All these Pliocene beds were referred to the Salada formation of Heim (1922, pp. 544–46) by the Marland Oil Company (1924, p. 43), Touwaide (1930, p. 120), and Locke (1935, p. 410). The writer has not used this term because, as stated, the Pliocene beds include three formations separated by unconformities; direct relation, furthermore, can be established with the type locality of the Salada, which is on the Pacific Coast of the peninsula, near Magdalena Bay; and the age of the Salada at the type locality was not precisely determined, the only fossils reported by Heim having been casts, undetermined except for generic identification. The Marland Oil Company report referred all the Pliocene beds of Baja California to the Salada formation; if it is desired to continue this usage, the name should refer to a group, to which the three formations proposed by the writer would belong.

The Marland Oil Company report (1924, p. 422) further states that the Salada is probably the marine equivalent of the Comondú (which was considered as probably Pliocene). This is certainly incorrect, for the most outstanding unconformity in the entire section near Santa Rosalía (aside from that on the plutonic basement) is between the Comondú and the overlying lower Pliocene beds. This unconformity not only represents a period of deformation and erosion but a complete change of geographic conditions—from sediments derived from the east, to sediments derived from the west, and the Pliocene beds were deposited on a highly irregular topographic surface carved in the Comondú. The same unconformity was noted by Anderson (1941) on islands in the Gulf.

The Pleistocene beds, consisting of a thin layer of fossilferous marine sandstone and conglomerate, which grade inland into non-marine conglomerate, are named the Santa Rosalía formation for the town of Santa Rosalía. The type locality is designated as fossil locality F9 on the south side of Arroyo de las Palmas, just below the top of the mesas on Lucifer claim No. 6.

The mesas northwest of Santa Rosalía are covered by Quaternary volcanic rocks, consisting of latite and basalt flows, breccia, pumice, welded tuff, and cinder cones. These are named the Tres Vírgenes volcanics, after the Tres Vírgenes volcanoes, active in historic time (Grewingk, 1848, pp. 143–144; Russell, 1897, p. 190; Nelson, 1921, p. 60), which, together with Cerro de Santa María, were the chief centers of eruption although other centers are scattered about the area. One such is the Las Palmas volcano, shown near the left-hand edge of section *AA* (Fig. 3), which contains, from bottom to top, a lens-shaped mass of volcanic breccia seemingly occupying a crater, latite flows, olivine-basalt flows, and basaltic cinders. The volcanic vent may not be exactly on the line of section as shown, but must be very near it.

Recent gravels and terrace deposits blanket the tops of the mesas and in various places spread down over the sides of the arroyos. Alluvium is found in the arroyos, in narrow beaches along the coast and in dry lake beds on top of the mesas.

GEOLOGIC HISTORY PRECEDING FORMATION OF GULF OF CALIFORNIA

ORIGIN OF COMONDÚ VOLCANICS (MIOCENE)

The bulk of the eastern half of the peninsula of Baja California, at least from Santa Rosalía as far south as Comondú and Loreto, is composed of the Comondú formation of Miocene age. Near Santa Rosalía this is a thick non-marine sequence of chiefly andesitic and basaltic flows, sill, pyroclastics, and intercalated sediments. It seems clear that Comondú formation was derived from the east, from the present site of the Gulf of California, as was recognized by Gabb (1868, p. 634). The volcanic members are most prominent toward the east; they wedge out westward into dominantly sedimentary layers; and the sediments, in turn, which are conglomeratic near the Gulf, become finer-grained westward so that the western facies of the formation is chiefly a terrestrial sandstone (part of the "mesa sandstone" of Gabb). The volcanics are found in many places directly along the Gulf coast; they make up the bulk of the Point Concepción peninsula and form the northern two-thirds of San Marcos Island. It is deduced, therefore, that while the Comondú volcanics were being deposited the Gulf of California either did not exist or at least had nothing like its present extent.

The age of the Comondú volcanics is established as middle or upper Miocene, from the fact that in the western part of the peninsula the formation rests unconformably on the Isidro formation of Heim (1922, p. 539–41), fossils from which are considered to be of lower Miocene age (Hertlein and Jordan, 1927, pp. 616–18; Loel and Corey, 1932, p. 160; Durham, 1944, p. 575); and that along the Gulf coast it is overlain unconformably by the lower Pliocene Boleo formation.

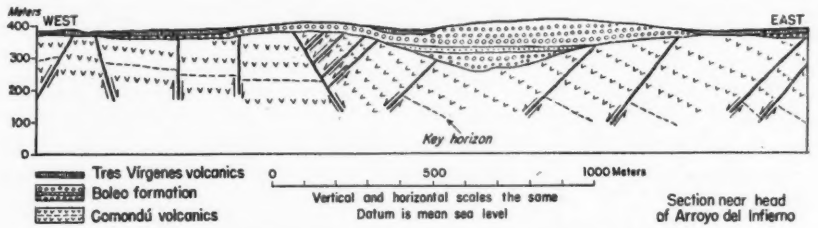
DEFORMATION OF COMONDÚ VOLCANICS

Over much of the peninsula of Baja California the Comondú formation has a gentle westward dip, as is shown in sections by Darton (1921, p. 723).[6] Near the edge of the Gulf, however, the formation was locally strongly deformed by faulting and steep eastward tilting. The results of this deformation are particularly well exposed near the head of Arroyo del Infierno, from 17 to 20 kilometers northwest of Santa Rosalía. The types of faulting and tilting found there are shown in Figure 4, which also illustrates the strong unconformity between the Comondú and Boleo formations. Elsewhere the Boleo and later formations have been subjected to similar faulting, though in general of less displacement, but these particular faults represent a pre-Boleo period of deformation (probably late Miocene).

Most of the faults cutting the Comondú volcanics are westward-dipping normal faults, forming a series of "compensating" eastward-dipping blocks. But at least one important fault has an eastward dip, the west side being upthrown. Perhaps faults of this type produced the uplift of the main range on the west; the eastward-tilted blocks adjoining it on the east may merely represent accompanying fragmentation. Further work over a broader area would probably be necessary

[6] The Comondú is shown in the west part of his sections as "mesa sandstone," grading eastward into "agglomerate, conglomerate, and igneous."

to prove this. It seems reasonable that the faulting observed may have been accompanied by downfaulting farther east, to form the deep basins at present occupied by the Gulf. This, of course, is largely speculative; but we do know, at least, that highlands occupied the present site of the Gulf during the time of



STRUCTURE SECTION SHOWING FAULTING OF COMONDU VOLCANICS

FIG. 4

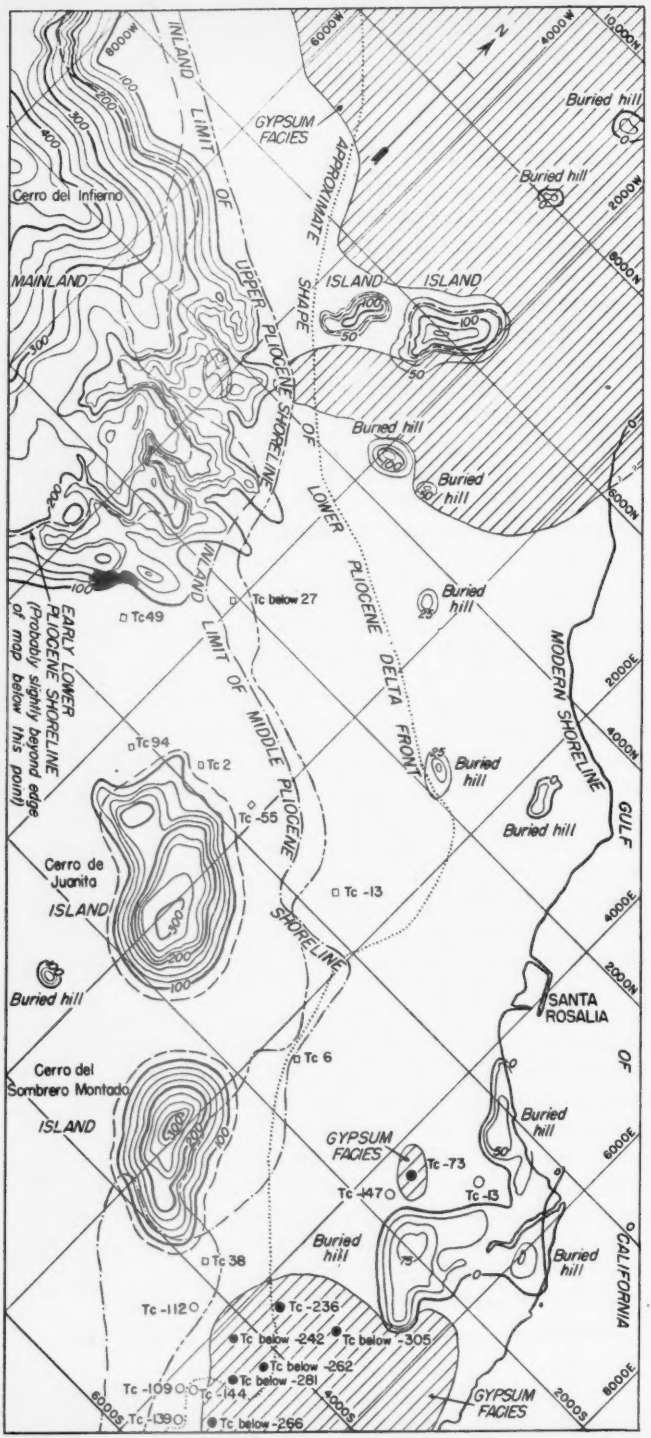
formation of the Comondú volcanics, and that large-scale sinking of these highlands must have occurred when the Gulf of California was formed.

PALEOTOPOGRAPHY OF COMONDÚ SURFACE AT TIME OF ENGULFMENT

Erosion following deformation of the Comondú volcanics had only reached a stage of late youth or early maturity when the Santa Rosalía area was engulfed by the sea. Valleys and ridges were submerged to form bays and headlands, expressed offshore by submarine hills and ridges, as well as by islands. The relief in the immediate vicinity of the shoreline, not considering the high Sierra de Santa Lucía at the west, was at least 450 meters. The shoreline probably somewhat resembled the modern shoreline at Concepción Bay, 60–100 kilometers south of Santa Rosalía (Fig. 1). At that place the shoreline, also carved in Comondú volcanics, exhibits steep slopes, headlands, and inlets, and small islands are present offshore.

The salient features of the pre-Boleo topography developed in the Comondú volcanics are shown in a paleotopographic map (Fig. 5), which indicates the more prominent islands, buried hills (submerged islands), and part of the mainland of early Pliocene time. The paleotopography is shown by approximate contours (form lines) with an interval of 25 meters drawn on the pre-Boleo surface of the Comondú. These are actually structure contours excepting that an attempt has been made to eliminate the effects of later faults, the offsets of which do not generally exceed 60 meters at any one place.[7] The form lines are based on present sea-level, not Pliocene sea-level, and they do not necessarily indicate relative Pliocene elevations, because of later tilting, but the attempt was made to show at least the shapes and relative positions of the salient Pliocene landforms.

[7] Structure-contour maps which include the effects of faulting are given in the report on the Boleo district.



EXPLANATION

UPPER PLIOCENE FACIES (Infierno formation)

Inland limit of marine sandstone (Probable maximum extent of upper Pliocene shoreline)

MIDDLE PLIOCENE FACIES (Gloria formation)

Inland limit of marine sandstone (Probable maximum extent of middle Pliocene shoreline)

LOWER PLIOCENE FACIES (Boleo formation)

Inland limit of basal marine limestone (Probable shoreline near beginning of lower Pliocene deposition)

Seaward limit of conglomerate no. 1 (Approximate shape of delta front near close of lower Pliocene deposition)

Extent of deposition of gypsum facies

SALIENT FEATURES OF TOPOGRAPHY AT BEGINNING OF PLIOCENE DEPOSITION

Form lines on early Pliocene surface of Comondú volcanics. Interval 25 meters; datum is present mean sea level. Topography of basins not shown. Form lines attempt to represent *shapes* of Pliocene landforms, but not necessarily true relative elevations

○ Tc -139 □ Tc below 27

Drill hole or shaft showing elevation in meters of top of Comondú surface. Minus figures are below sea level. "Tc below 27" means Comondú is unknown depth below elevation given

● Drill hole indicating presence of gypsum

○ □ Drill hole or shaft indicating absence of gypsum

0 1 2 3

Scale in kilometers

Coordinates same as on geologic map

PLIOCENE PALEOTOPOGRAPHIC, PALEOGEOGRAPHIC, AND FACIES MAP OF THE SANTA ROSALIA AREA

FIG. 5

Where the Comondú is buried by sediments the contours are based on data from mine workings and drill holes. In areas where the Comondú has been exposed by erosion, reconstruction of the original surface is greatly facilitated by the persistence of a thin basal marine limestone of the overlying Boleo formation, which, being resistant to erosion, is commonly preserved on dip slopes and which beautifully portrays the irregularities in the Comondú surface. Even where not shown on the geologic map a few tiny remnants of the Boleo limestone were found in places clinging to the Comondú surface, thus revealing its shape. In the high areas and islands where the Comondú was never covered by sediments its Pliocene surface can only be approximated, but it is assumed not to have been greatly modified by erosion except by recent canyon-cutting. In the undissected areas between the arroyos and on the rounded tops of the higher hills erosion is not believed to have been great since Boleo time. Any error in this regard, however, tends to minimize rather than exaggerate the relief, for if the amount of later erosion is actually greater than assumed then the original relief was even higher than the paleotopographic map indicates.

The map shows eleven isolated buried hills and four islands, besides part of the Pliocene mainland around Cerro del Infierno with its intricate bays and headlands, extending offshore into submarine hills. The topography of the basins is not shown, and there may be other undiscovered buried hills in the area.

Two of the principal islands were Cerro de Juanita and Cerro del Sombrero Montado, both of which have present altitudes of slightly over 310 meters above sea-level. Cerro de Juanita rises 40 meters above the highest adjacent Pliocene sediments, and 370 meters above the lowest Pliocene sediments in the adjacent basin. Cerro del Sombrero Montado extends 70 meters above the highest adjacent Pliocene sediments, and 420 meters above the lowest Pliocene sediments in the adjacent basin. The highest part of the Pliocene mainland shown on the map (although the Sierra de Santa Lucía on the west is much higher) is Cerro del Infierno, reaching a present altitude of 490 meters, which is 120 meters above the highest adjacent Pliocene sediments and 450 meters above the lowest Pliocene sediments in the adjacent basin. The local relief of the Comondú surface, therefore, that is, the relief between the top of a hill and the bottom of a valley adjacent to it, was 370, 420, and 450 meters, respectively, for the three hills mentioned. These are minimum figures, as they do not allow for any erosion of the tops of the hills since the early Pliocene. The maximum present relief of the Comondú surface in the area mapped, between the highest point on Cerro del Infierno and the lowest point where it is buried below Arroyo de Santa Agueda (more than 305 meters below sea-level, as shown by drill holes) is about 800 meters, but this has probably been increased by tilting since Pliocene time.

DATE OF ENGULFMENT

The earliest marine beds deposited in the Gulf of California in the vicinity of Santa Rosalía are of lower Pliocene age, according to determinations by H. E.

Vokes of fossils collected by the writer from the Boleo formation. They are tentatively correlated with the Imperial formation of southeastern California, which is regarded as having been deposited in the upper end of the ancestral Gulf of California. It should be noted that some paleontologists consider the Imperial formation of upper Miocene rather than lower Pliocene age; this difference of opinion might also apply to the Boleo formation. As far as the writer is aware, no older marine sediments that could have been deposited in the Gulf are known at any point. Marine Tertiary sediments are mentioned by King (1939, p. 1693) as having been penetrated in a deep well at Empalme, Sonora, on the east side of the Gulf, but the exact age is not given.

The date of engulfment, therefore, at least in the vicinity of Santa Rosalía and most likely elsewhere, was at the beginning of the Pliocene (or perhaps late in the Miocene, depending on the interpretation of the age of the fossils of the Imperial formation). The engulfment probably did not start any earlier than late Miocene, at least, as it evidently postdates the deposition of the Comondú formation of middle or upper Miocene age.

SEDIMENTATION ON EDGE OF GULF DURING PLIOCENE AND PLEISTOCENE

BOLEO FORMATION (LOWER PLIOCENE)

Non-marine basal conglomerate.—Locally sedimentation of the Boleo formation was initiated with a coarse non-marine basal conglomerate that is found only in small areas around steep ancestral hills, ridges, and islands of the Comondú volcanics. The conglomerate has a maximum thickness of 10 meters, but wedges out not far from the Comondú hills, and over most of the area mapped near Santa Rosalía it was never deposited. From the coarseness, angularity, and extremely poor sorting of the constituent fragments, there seems little doubt that this conglomerate is of terrestrial origin. It appears to represent fanglomerates, and perhaps in some places talus deposits, that accumulated about the steep slopes of the rugged hills and ridges carved in the Comondú volcanics before their inundation by the waters of the Gulf of California.

Basal marine limestone.—The basal marine deposit of the Boleo formation is a peculiar thin layer of impure limestone. Where the basal conglomerate is present, the limestone rests on top of it, but over large areas the limestone rests directly on the eroded surface of the Comondú volcanics. It averages only 1–2 meters in thickness, only rarely thickening to more than 5 meters. The rock has formerly been called a dolomite, but analyses by the Boleo company indicate that, although magnesia is present locally, it is more commonly absent or nearly so. The limestone is dark brown, impure, and tuffaceous; some specimens, in fact, could be called calcareous tuff. It is commonly ferruginous and manganiferous. The rock contains fairly abundant but very poorly preserved casts and molds of marine fossils.

At the present time the limestone is exposed particularly around the edges of the buried hills of Comondú volcanics. It completely covers the smaller hills,

but wedges out against the higher ridges and islands that were never completely covered by the sea. The limestone follows all the topographic irregularities of the Comondú surface on which it was deposited. Steep dips are common, and in places the limestone clings to remarkably steep slopes and even small cliffs in the Comondú volcanics, to which it is literally plastered. The origin of the limestone is obscure, but it may have been formed partly through the agency of organisms that adhered to the rocky slopes, headlands, and islands of the Comondú volcanics as they were engulfed by the sea. Perhaps unusual climatic factors or chemical conditions of the sea water were involved in its origin; no similar deposit, at any rate, was formed at any later time in the area under discussion. Because of its irregular surface of deposition the limestone transgresses stratigraphic boundaries and is overlain in various places by different horizons of the Boleo formation.

Gypsum.—Deposits of gypsum as much as 80 meters thick are found in local areas in the Boleo formation. The gypsum generally overlies the basal marine limestone, but in some places it rests directly on the Comondú volcanics, and elsewhere it rests on conglomerate or tuff a short distance above the base of the formation. It occurs in isolated areas, and in places wedges out rather abruptly around the margins. A facies map (Fig. 5) shows the approximate areas in which gypsum was deposited, judged from outcrops and drill holes. Thick gypsum deposits, probably of the same age, occur on the southern end of San Marcos Island, where they have been mined for many years (although operations were interrupted by World War II). The gypsum deposits may represent a temporary epoch of desiccation, following the first marine invasion, caused by a slight elevation of the land (or lowering of the sea), leaving scattered lagoons. Touwaide (1930, p. 119) presents an alternative hypothesis that the gypsum may be of hydrothermal origin, perhaps produced by submarine springs on the sea floor.

Tuff and tuffaceous conglomerate.—The bulk of the Boleo formation is composed of alternating layers of tuff and tuffaceous conglomerate, grading into tuffaceous sandstone. There are at least five main conglomerate lenses, each overlain by a layer of latitic to andesitic tuff, which grades upward from clayey tuff into sandy tuff. Copper and manganese deposits, believed to be of hydrothermal origin, are found in the beds of clayey tuff. The four principal ore beds have been numbered by the mine operators, starting with number 1 at the top and proceeding to number 4 at the base. A still higher bed, found only in the southeast part of the area, is called number 0. The same numbers have been applied by the writer to the conglomerates immediately underlying each ore bed.

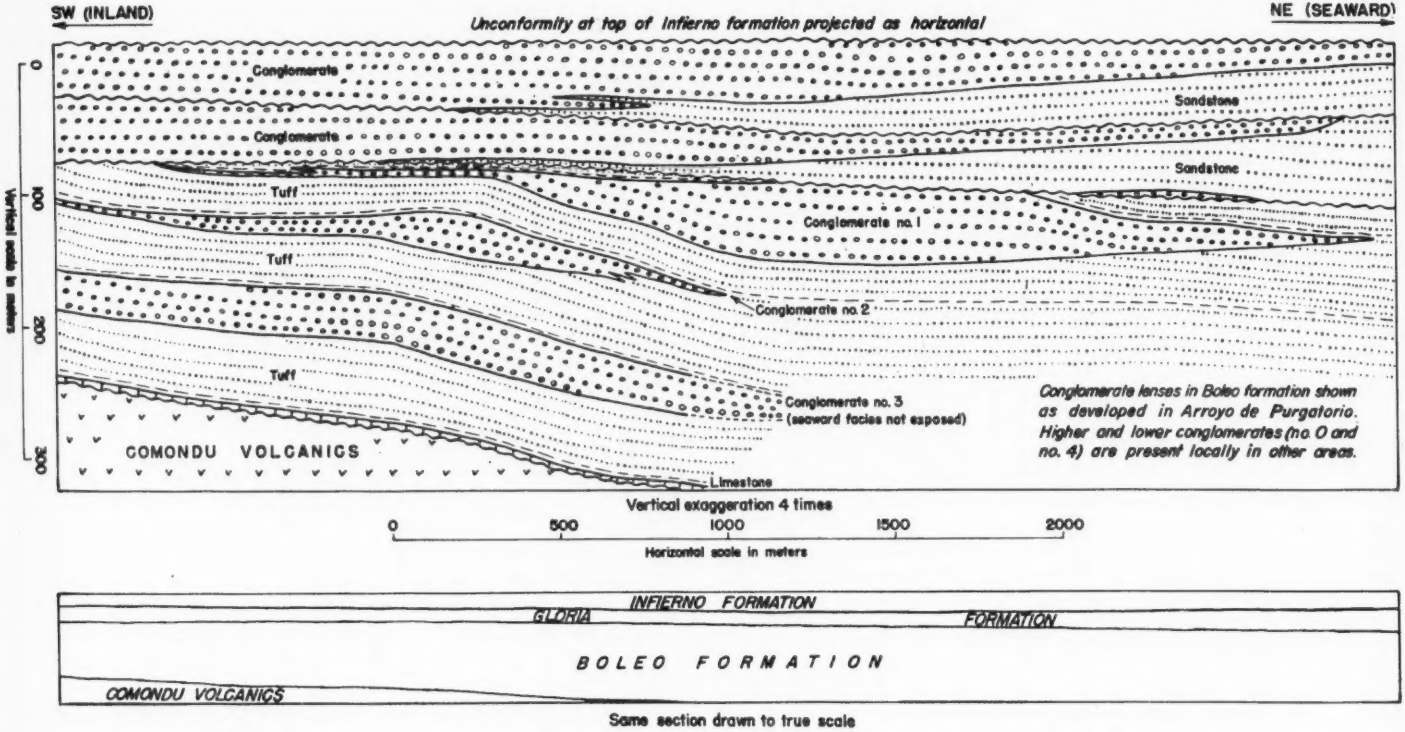
In no one place is the complete section present. Beds may be missing from the base due to non-deposition against topographic highs of the Comondú surface. Thus the lowest conglomerate, number 4, is found only in restricted local areas; and conglomerate number 3 is missing from all the southeast part of the area (righ-hand part of section *AA'*, Fig. 3). Conglomerate number 2 is absent in some places, and of course the entire formation wedges out against the islands, and higher parts of the Pliocene mainland. Beds may be missing from the top,

likewise, because of erosion represented by the unconformity at the base of the Gloria formation. This erosion has removed conglomerate number 0 from the the entire northwest part of the area (if it was ever deposited there), has removed conglomerate number 1 from considerable areas, and in places has also removed conglomerate number 2. Thus the section at any particular place depends upon what has been cut out from the top by erosion or from the bottom by topographic irregularity of the depositional surface. In the northwest area the average section contains conglomerates 1, 2, and 3, whereas in the southeast area it consists of conglomerates 0, 1, and 2, with the corresponding interbedded tuffs.

The conglomerate beds grade seaward into tuffaceous sandstone, a fact recognized by Touwaide (1930, p. 121) and Locke (1935, pp. 410–11). Additional facts of interest are that each conglomerate is a lens, not only wedging out seaward but also thinning farther inland, and that the thickest part of each successively higher lens extends farther seaward. Such, at least, is the situation with conglomerates 1, 2, and 3 as exposed in Arroyo de Purgatorio, and it seems to apply also to conglomerate number 4. The resulting cross section is believed to be representative of deltaic deposits (Fig. 6). It indicates a gradual filling of the basin, probably accompanied by a seaward migration of the shoreline.

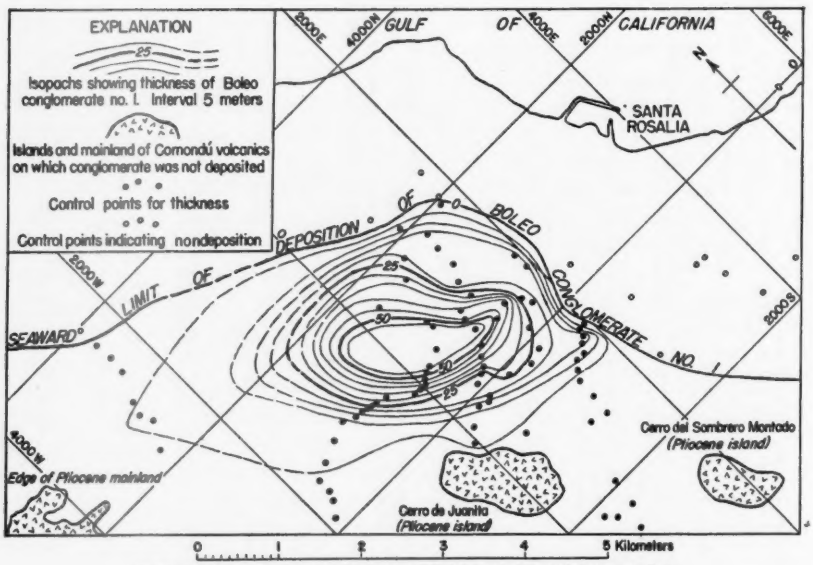
The shape of one of these lenses (that of conglomerate number 1) in plan view is shown by an isopach map in Figure 7. This map shows that, proceeding seaward, the lens increases in a short distance from a thickness of 5 meters to 55 meters, then wedges out altogether within a distance of 2 kilometers from the center of the lens. Around the edge of the lens, excepting in the seaward direction, the conglomerate extends as a thin blanket, having an average thickness of 3 meters over a broad area extending for several kilometers beyond the borders of the map. A reasonable interpretation of this lens seems to be that a large river may have emptied into the sea somewhere between Cerro de Juanita and the edge of the Pliocene mainland shown on the map, building out a delta, whereas the thin blanket of conglomerate extending northwest and southeast represents deposition on a piedmont plain, along the flanks of a mountain range composed of the Comondú volcanics.

"Cinta colorada"—a time horizon.—A significant time horizon in the Boleo formation is the "cinta colorada," a conspicuous reddish to purplish thin layer of coarse-grained pure tuff, a few decimeters to a meter in thickness, composed mainly of volcanic cinders of coarse ash to lapilli size. This is found in various parts of the Boleo district, without exception in sediments between ore beds 2 and 3, and is believed to have been deposited everywhere at the same time. It may have been deposited within a very brief period of geologic time, perhaps as the result of a single volcanic eruption. In detail, this layer transgresses lithologic boundaries—particularly the contact separating the base of conglomerate number 2 from tuffaceous sandstone below—indicating that such lithologic contacts are not true time boundaries. In Arroyo de Purgatorio, for example, the "cinta



GENERALIZED STRATIGRAPHIC SECTION SHOWING FACIES CHANGES IN THE PLIOCENE BEDS OF THE SANTA ROSALIA AREA

FIG. 6



ISOPACH MAP OF A LOWER PLIOCENE CONGLOMERATE LENS

FIG. 7

colorada" lies within conglomerate number 2 in the inland area, but seaward it moves down to the base of the conglomerate where it continues for some distance; still farther seaward it moves down into the sandstone. This means that the conglomerate in the inland area is equivalent in time to part of the sandstone in the seaward area—just as would be deduced for deltaic deposits. The term "time horizon" is employed in its usual stratigraphic sense, but in this case it does not imply that the bed was ever horizontal; there is evidence, rather, that this, like the surrounding beds, was deposited with an appreciable initial dip.

The "cinta colorada," although it must have been deposited as a continuous bed, is not now continuous; in many places it has been scoured out and the intervening space filled in with conglomerate. Local scouring, channeling, cross-bedding, and diastems are, in fact, prevalent throughout the Boleo formation—the natural results of rapid deposition near a shoreline.

Origin of formation.—The Boleo formation is probably partly marine and partly non-marine. The limestone is definitely marine, and marine fossils have been found in a few sandstone lenses above the limestone near the base of the formation. The bulk of the formation contains no fossils, however, although fragments of petrified wood and carbonaceous material are present. Probably at least the inland facies of the conglomerates are non-marine, as they become coarser-grained and more poorly sorted inland. But it is difficult to draw any line between

the marine and non-marine beds. Such would probably be the case, as a matter of fact, in many recent deltas.

Conditions for the formation of the Boleo conglomerate deposits are probably similar to those existing to-day in the San Bruno plain, south of Santa Rosalía. This is a broad piedmont plain along which gravel deposits are being formed from débris washed down from the Sierra de Santa Lucía. The gravel deposits extend seaward into the Gulf, and if an uplift were to occur to-day, it would probably be difficult to draw a precise line between the marine and non-marine deposits. A few sandy beaches occur along the Gulf, but most of the beaches are gravelly.

The main difference between the Boleo formation and the recent deposits lies in the tuffaceous character of the Boleo, which is the result of successive epochs of explosive volcanic activity. The volcanic eruptions not only produced layers of pure tuff in the section, but are also believed to have greatly affected the ensuing sequence of sedimentation. The volcanic eruptions must have deposited a mantle of ash over the entire surrounding countryside—not only over the areas of deposition, which we may now observe, but also over the areas that were being actively eroded. The result would be a change in the source material of the succeeding sediments. Whereas the source previously consisted exclusively of Comondú volcanics (which comprise nearly 100 per cent of the pebbles in the conglomerates), for a time after each eruption the only source material would be ash, until erosion proceeded sufficiently to remove the ash cover in various places and again expose the Comondú volcanics.

The sequence of sediments bears out this interpretation. Only the lower part of each tuff member appears to consist of pure tuff (with some exceptions); the upper part appears more likely to have resulted from the reworking of tuffaceous material. There is a gradual coarsening from bottom to top until conglomerate is reached. The base of each conglomerate is generally gradational and interfingering, probably indicating a gradual admixture of Comondú volcanics (in the form of pebbles) and ash in the source material. The top of each conglomerate, in contrast, is sharply defined, being overlain directly by very persistent clayey tuff layers (some of which are traceable for at least 20 kilometers), which must be the product of violent volcanic eruptions.

In summary, the Boleo sedimentary pattern seems to represent the following conditions: (1) the normal gradation, in deltaic deposits adjacent to a rugged topography, from conglomerate inland to sandstone seaward; (2) the migration of this facies change farther seaward with the passage of time as the basin filled in, probably accompanied as well by continued uplift of the landmass; and (3) the abrupt interruption of this process from time to time by explosive volcanic eruptions, resulting first in the deposition of pure tuff, followed by reworked tuff, grading upward through mixed tuffaceous and detrital material until the original conditions of sedimentation were restored.

Fossils and age.—The basal limestone contains numerous, poorly preserved fossils, including unidentified pelecypods, minute gastropods, a cerithiid, and a

new species of *Laevicardium*. A fossiliferous sandstone above the limestone in Cañada de la Gloria yielded the following species, as identified by H. E. Vokes (locality F3):[8]

Species	*Known Range*
Ostrea vespertina Conrad	Lower to upper Pliocene
Pecten, (*Pecten*) *beali* Hertlein	Lower Pliocene
Pecten (*Euvola*) *keepi* Arnold	Lower Pliocene
Aequipecten abietis (Jordan and Hertlein)	Lower to upper Pliocene

Vokes considers this fauna to be of lower Pliocene age, contemporaneous with the fauna of the Imperial formation of southeastern California.

Lower Pliocene (*Boleo*) *fauna from Point Concepción.*—Another fauna apparently contemporaneous with that of the Imperial formation was collected by the writer at Santo Domingo Bay, an inlet of Concepción Bay near Point Concepción, 70 kilometers southeast of Santa Rosalía, at a locality pointed out by James A. Noble. This occurs in a gently dipping sandstone with conglomeratic layers, exposed directly along the shore and evidently resting unconformably on Comondú volcanics. From the lithology alone, these beds could not be correlated with the formations at Santa Rosalía, but the fossils indicate the same age as for the Boleo formation. From this locality the following fossils were identified by H. E. Vokes (United States National Museum locality 15615):

Glycymeris gigantea Reeve
Glycymeris chemnitzii Dall
Glycymeris n. sp. aff. *maculata* Reeve
Ostrea cf. *jacobaea* Rochebrune
Ostrea sp.
Aequipecten sp. (n. sp.?)
Chlamys n. sp.
Palinopecten sp. aff. *bakeri* n. subsp. Durham Ms.
Spondylus aff. *bostrychites* Guppy
Crassatella n. sp. aff. *gibbosa* Sowerby
Fragum n. sp.
Chione succincta Valenciennes
Chione (*Lirophora*) *mariae* D'Orbigny
Corbula, 2 sp. indet.
Turritella imperialis Hanna
Turritella n. sp.?
Fusinus ? sp. indet.
Oliva spicata Bolten
Terebra n. sp.? (aff. *interlineata* Deshayes)
Conus n. sp.

Concerning this fauna, Vokes states: "The presence of *Turritella imperialis* Hanna clearly allies this fauna with that of the Imperial formation, and it must share with that formation the uncertainty as to its age. Present opinion tends toward assigning it to the lower Pliocene (see Weaver *et al.*, 1944, correlation table facing p. 596), and the number of Recent species recognized does not suggest any older assignment for this fauna."

GLORIA FORMATION (MIDDLE PLIOCENE)

The middle Pliocene Gloria formation consists of a local thin basal conglomerate, a fairly thick sandstone, and overlying conglomerate. The basal conglomerate is generally a meter or so in thickness, and is found only in local areas. The sandstone wedges out inland and thickens seaward. In the inland area it is a thin layer, 2–3 meters thick, which is highly fossiliferous. Echinoids are locally prominent in this shoreward facies although elsewhere Pectens are dominant. Farther seaward it grades into a sequence of siltstones and clays at least 70 meters

[8] The fossil localities are plotted on the map in Figure 3.

thick, containing interbedded sandy layers. This facies is particularly prominent in the northern part of the district, north of Arroyo de Purgatorio. At the top of the formation is a conglomerate that thins out seaward and thickens inland, attaining a thickness of about 50 meters. It grades inland into what is probably a non-marine facies.

In places there is a marked angular unconformity between the Boleo and Gloria formations, particularly in the inland area where the thin fossiliferous sandstone occurs. This cuts across structural highs in the Boleo formation, to the extent that the highest beds of the latter are cut out in various places. But this unconformity seems to die out seaward, which is interpreted to mean that tilting raised the inland area above sea-level, resulting in erosion, while the seaward area remained below sea-level, where deposition may have continued more or less uninterruptedly.

Fossils collected by the writer from the Gloria formation and identified by H. E. Vokes are listed in Table I. Among the more diagnostic species are the new species described in a manuscript by Durham, *Aequipecten* n. sp. A, *Aequipecten* aff. n. sp. B, and *Patinopecten bakeri* (Hanna and Hertlein) n. subsp., which, according to Durham, represent the middle Pliocene.

INFIERNO FORMATION (UPPER PLIOCENE)

The upper Pliocene Infierno formation consists of a marine fossiliferous sandstone and overlying conglomerate. The sandstone dies out inland, in places wedging out into two or three thin layers interfingered with conglomerate. In places isolated sandy lenses are intercalated in the conglomerate, thins seaward and thickens inland, where it becomes coarser-grained and more poorly sorted, probably grading into a non-marine facies.

An angular unconformity between the Gloria and Infierno formations was established with certainty at two widely separated places: (1) the type locality of the Infierno formation on the south side of Arroyo del Infierno, and (2) on the south side of Arroyo de Santa Agueda, near its mouth, where there is a prominent angular unconformity with a local difference in dip of about 15°. In a few other localities such an unconformity was thought to be present, but over much of the area no unconformity may be discerned. Probably a slight uplift, accentuated by warping in local areas, separated the epochs of deposition of the two formations.

Fossils collected from the Infierno formation and identified by H. E. Vokes are listed in Table II. Probably the most diagnostic form is the *Patinopecten* n. sp. Durham Ms., which, according to Durham, is representative of the upper Pliocene. Vokes thinks that probably all the localities listed in Table II belong to the upper Pliocene, except for localities F24 and F26, which may be middle or upper Pliocene. Because of the field relations, these two localities are tentatively placed with the Infierno formation.

The contact mapped in the field between the Gloria and Infierno formations

TABLE I

FOSSILS FROM GLORIA FORMATION (MIDDLE PLIOCENE)

Species	*F7*	*F8*	*F11*	*F13*	*F15*	*F18*	*F19*	*F20*	*F27*
Encope michelini Agassiz[a]				X		X?			
Clypeaster speciosus Verrill[b]									X[b]
Ostrea cf. *angelica* Rochebrune		X							
Ostrea cf. *erici* Hertlein					X				
Ostrea megodon Hanley	X	X	X				X	X	
Ostrea vespertina Conrad	X		X					X	
Pecten (*Euvola*) *cf. refugioensis* Hertlein			X	X		X?	X		
Pecten (*Euvola*) n. sp.								X	
Pecten (*Nodipecten*) *subnodosus* Sowerby			X						
Aequipecten abietis (Jordan and Hertlein)		X				X?			
Aequipecten callidus (Hertlein)			X						
Aequipecten circularis (Sowerby)								X	
Aequipecten cf. *subdolus* (Hertlein)			X						
Aequipecten n. sp. Durham Ms. (A)	X								
Aequipecten aff. n. sp. Durham Ms. (B)	X								
Aequipecten n. sp.	X								
Aequipecten sp. indet.					X				
Chlamys? n. sp. A			X				X	X	
Patinopecten bakeri (Hanna and Hertlein) n. subsp. Durham Ms.	X						X		
Patinopecten bakeri (Hanna and Hertlein) var.		X							
Patinopecten sp. aff. *bakeri* (Hanna and Hertlein)			X						
Patinopecten cf. *stearnsii* (Dall)		X							
Patinopecten n. sp.	X								
Patinopecten n. sp.?[c]			X				X		
Patinopecten n. sp.? B			X						
Patinopecten sp.				X					
Anomia sp. indet.	X								
Placunanomia hannibali Jordan and Hertlein[d]								X	
Dosinia? sp. (not *D. ponderosa*)			X						
Turritella aff. *gonostoma* Valenciennes	X								
Balanus sp.	X								

[a] An Atlantic species. Poriferous zones wider than in the very similar Pacific species *Encope micropora* Agassiz.
[b] It is not absolutely certain that field locality F27, containing *Clypeaster speciosus* Verrill, is in the Gloria formation.
[c] The *Patinopecten* n. sp.? from localities F11 and F19 is close to *Patinopecten* n. sp. from locality F7, but has fewer (21 instead of 25) ribs.
[d] *Placunanomia hannibali* Jordan and Hertlein has been reported only from upper Pliocene deposits. For this reason Vokes is uncertain of the age of locality F20, although the *Chlamys ?* n. sp. A at that locality seems to be the same as in localities F11 and F19. From the field relations locality F20 appears to belong to the Gloria formation.

may not necessarily coincide everywhere with the time boundary between the middle and upper Pliocene which seems to demark the fossil collections from the two formations. The contact was based on unconformities wherever possible, but where based merely on lithology the mapped contact may very well transgress time horizons. In the inland area, where both the Gloria and Infierno formations (and probably also the Santa Rosalía formation) grade into non-marine conglomerate, it becomes practically impossible to separate the formations. For this reason, they have been mapped in that area as "undifferentiated post-Boleo beds."

SANTA ROSALÍA FORMATION (PLEISTOCENE)

The Pleistocene Santa Rosalía formation consists of a thin fossiliferous sandstone and conglomerate near the tops of the mesas in the Santa Rosalía area. The

TABLE II

FOSSILS FROM INFIERNO FORMATION (UPPER PLIOCENE)

Species	*F10*	*F12*	*F14*	*F16*	*F21*	*F24*	*F25*	*F26*	*F28*
Dendraster excentricus (Eschscholtz) var.	....	....	....	....	....	....	....	....	X
Lytechinus? sp. (fragment)	....	....	....	....	....	....	....	....	X
Meoma ventricosa Lamarck ?[a]	....	....	....	....	....	....	....	....	X
Glycymeris sp. indet. (cast)	....	....	....	....	....	....	....	X	....
Anadara sp. indet. (cast)	....	....	....	....	....	....	....	X	....
Ostrea cf. *angelica* Rochebrune	....	....	....	....	....	....	....	X	....
Ostrea aff. *cumingiana*, Dunker[b]	....	X	....	....	....	X	....	X	....
Ostrea fischeri Dall	X	....	....	....	....	....	....	....	cf.
Ostrea megodon Hanley	....	X	X	....	X	X	....	X	X
Ostrea vespertina Conrad	....	X	X	....	....	....	....	....	....
Pecten bellus Conrad n. subsp.[c]	....	....	....	....	....	....	....	....	X
Pecten (*Nodipecten*) *subnodosus* Sowerby	....	X	X	....	....	....	....	....	....
"*Pecten*" sp.	X	....	....	....	....	....	....	....	....
Aequipecten abietis (Jordan and Hertlein)	X	X	X	....	X	....	....	X	X
Aequipecten callidus (Hertlein)	....	X	....	....	....	....	....	....	....
Aequipecten circularis (Sowerby)	....	X	....	....	....	....	X	....	....
Aequipecten purpuratus Lamarck	....	....	....	....	X	....	X	X	....
Aequipecten subdolus (Hertlein)	....	....	....	....	....	X	....	....	....
Patinopecten bakeri (Hanna and Hertlein) aff. n. subsp. Durham Ms.	....	X	....	....	....	....	....	....	....
Patinopecten n. sp. Durham Ms.[d]	X	....	X	....	aff	....	....	....	X
Patinopecten sp.[e]	....	....	....	....	....	....	....	X	....
Patinopecten sp.	....	....	....	X	....	....	....	....	....
Placunanomia hannibali Jordan and Hertlein	....	X	X	....	....	....	X	....	....
Cardita sp. indet. (cast)	....	....	....	....	....	....	....	X	....
Chione (*Lirophora*) sp. indet. (cast)	....	....	....	....	....	....	....	X	....
Corbula sp. indet. (cast)	....	....	....	....	....	....	....	X	....
Panope cf. *generosa* Gould (cast)	....	....	....	....	....	....	....	X	....
Turritella gonostoma Valenciennes	....	aff	....	....	X	....	....	X	....
Crucibulum sp. cf. *spinosum* (Sowerby)	X	....	....	....	....	....	....	....	....
Conus sp. (cast)	....	....	....	....	....	....	....	X	....
Balanus sp.	....	X	....	....	....	....	....	....	X

[a] An Atlantic species, very close to *Meoma grandis* Gray, a Pacific species.
[b] Much larger and more evenly sculptured than any in the Recent collections of the National Museum.
[c] Has 22 instead of 15–17 radiating ribs that are proportionately wider and more round-topped. Interspaces of left valves bear a riblet, as in *Pecten bellus*—absent in *P. heimi* Hertlein, *P. hemphilli* Dall, *et cetera*.
[d] An upper Pliocene species, according to Durham.
[e] Very close to the upper Pliocene form listed above as *Patinopecten* n. sp. Durham MS., but contains only 19–20 ribs instead of 23–25.

fossiliferous beds probably give way inland to a non-marine conglomerate. Pumice fragments appear in some of the fossiliferous conglomerate, probably representing the initiation of the Tres Vírgenes epoch of volcanic activity, which continued into Recent time. The formation is exposed only in scattered outcrops, having been largely eroded or else covered by recent gravel deposits that blanket the tops of the mesas. In a few places an angular unconformity may be seen at the base of the Santa Rosalía formation.

Fossils from the Santa Rosalía formation, identified by H. E. Vokes, are listed in Table III. Vokes states that the assemblage from locality F17 is a Pleistocene fauna. Regarding locality F9, he states that the traces of color patterns preserved in a number of the specimens, and the known range of the few forms previously reported, which have been listed by Durham, suggest a Pleistocene age.

TABLE III

FOSSILS FROM SANTA ROSALÍA FORMATION (PLEISTOCENE)

Species	*F8*	*F9*[a]	*F17*
Anadara (*Larkinia*) *multicostata* (Sowerby)	.....	X	.....
Ostrea cumingiana Dunker	X	.....	.....
Ostrea cumingiana Dunker or *jacobaea* Rochebrune	.....	.....	X
Ostrea fischeri Dall	X	.....	.....
Aequipecten circularis (Sowerby)[b]	X	.....	.....
Aequipecten cf. *purpuratus* (Lamarck)	.....	.....	X
Aequipecten sp.	.....	X	.....
Spondylus cf. *princeps* Broderip	.....	.....	X
Divaricella eburnea (Reeve)	.....	X	.....
Americardia biangulatum (Sowerby)	.....	X	.....
Dosinia (*Dosinidia*) *ponderosa* (Gray)	.....	.....	X
Dosinia (*Dosinidia*) n. sp.	.....	X	.....
Chione fluctifraga (Sowerby)	.....	.....	X
Chione succincta (Valenciennes)	.....	X	.....
Chione sp. aff. *kellettii* (Hinds)	.....	X	.....
Megapitaria squalida (Sowerby) (immature specimen)	.....	X	.....
Megapitaria aurantiacus (Sowerby) n. subsp.	.....	X	.....
Pitar n. sp.	.....	X	.....
Cerithium uncinatum Gmelin	.....	X	.....
Crepidula sp. (fragments)	.....	X	.....
Nassarius sp. (immature specimen)	.....	X	.....
Parametaria coniformis (Sowerby)	.....	X	.....
Oliva cf. *venulata* Lamarck	.....	X	.....
Olivella n. sp.?	.....	X	.....
Terebra variegata Gray	.....	X	.....
Bullaria sp. (fragments)	.....	X	.....
Balanus sp.	.....	X	.....
Echinoid fragments	X	.....	.....

[a] At this locality occur, in addition, a number of microscopic gastropods which have not been studied.
[b] Specimens show dim remnants of color patterns.

He states that locality F8 may be of uppermost Pliocene or Pleistocene age, the latter being favored by dim remnants of color patterns on some of the specimens of *Aequipecten circularis*.

SUMMARY OF FACIES CHANGES

The various facies changes related to the rugged shoreline conditions existing along the western margin of the Gulf of California during the Pliocene and Pleistocene may be summarized as follows.

1. Lower Pliocene Boleo formation
   a. Non-marine basal conglomerate deposited only locally around steep slopes
   b. Basal marine limestone deposited on irregular erosion surface of Comondú volcanics
   c. Gypsum deposited in isolated, local, basin-like areas
   d. Conglomerate lenses having deltaic structure wedge out seaward into sandstones; successively higher lenses extend farther seaward
   e. Normal conglomerate-sandstone deposition interrupted at least five times by explosive volcanic eruptions, producing layers of tuff
2. Middle Pliocene Gloria formation
   a. Basal conglomerate deposited only locally
   b. Marine sandstone wedges out into conglomerate inland; thickens seaward and grades into thick siltstones and clays
   c. Conglomerate thins down seaward, thickens inland and grades into non-marine facies

3. Upper Pliocene Infierno formation
   a. Marine sandstone wedges out into conglomerate inland
   b. Conglomerate thins down seaward, thickens inland and grades into non-marine facies
4. Pleistocene Santa Rosalia formation
   a. Marine sandstone and conglomerate probably give way inland to non-marine conglomerate

Many of these facies changes are illustrated by the stratigraphic section in Figure 6, and some of the more prominent facies lines are indicated in the paleotopographic, paleogeographic, and facies map in Figure 5. The facies lines show that, except in small areas, the successively younger shorelines moved progressively seaward, and this applies likewise to the modern shoreline. This seaward migration of the shorelines is in part the natural result of accumulation of sediments along the shore, but it was accentuated by successive uplifts of the inland area. Insufficient data were found to permit drawing of the Pleistocene shoreline, but it apparently extended no farther inland than did that of the upper Pliocene.

INITIAL STRUCTURES PRODUCED BY BURIED TOPOGRAPHY

GENERAL FEATURES

The most unique structures of the Pliocene and Pleistocene formations are those resulting from deposition on an irregular topographic surface. The sea floor was an erosion surface of high relief carved in the Comondú volcanics, which was submerged while the area was still in a geomorphic stage of late youth or early maturity. The irregular surface of the basement was recognized by Touwaide (1930, pp. 120, 123, 125) and Locke (1935, p. 410), and a similar irregular surface of the Comondú below Pliocene sediments was noted by Anderson (1941) on the islands studied by him in the Gulf of California.

As a result of sedimentation on this irregular floor, structures simulating anticlines were produced over the original hills, and others resembling synclines were formed in the original valleys or basins. The fact that these were not caused by deformation can be seen clearly by examining the basal contacts of the sediments on top of the Comondú volcanics. It may be seen that the structures are parallel to the original topography on the Comondú rocks, and that the latter do not participate in the folds of the sediments. The structure of the Comondú volcanics, in fact, is entirely independent of that of the overlying beds; the volcanics may dip more steeply or more gently than the sediments, and in some places they even dip in the opposite direction.

The folds do not have regular, more or less parallel axes as do folds produced by compression; rather, the axes are irregular, more or less dendritic, reflecting the trends of topographic features (hills and valleys) over which they were developed. Along the edge of the original Pliocene mainland there is evidence of an original dendritic drainage pattern in the Comondú volcanics, in which the valleys submerged to form bays, were filled in with sediments possessing a synclinal structure, while the intervening ridges formed headlands, remaining partly above sea-level but submerged farther out to form buried hills covered by sediments with

an initial anticlinal structure. Such a drainage pattern is shown by the paleotopographic map in the upper left-hand corner of Figure 5, and the resulting structures are indicated in sections AA' and BB' (Fig. 3), in the vicinity of their mutual intersection near the Texcoco mine.

The lowest sediments follow the original topography most closely, passing over the tops of the smaller buried hills, but wedging out against the sides of the larger more rugged ones. The basal marine limestone of the Boleo formation thus shows steeper dips, commonly 30° or more, than do any of the higher beds, and at first glance appears to have been highly folded—an anomalous and erroneous picture since the underlying rocks have not been folded at all, and the overlying sediments dip more gently than the limestone. Succeeding sediments wedged out against the hills and filled in the basins, so that successively higher beds show less and less the effect of the original topography, although dips of 10° or more occur throughout the Boleo formation. The post-Boleo formations show even less the effect of the irregular floor, because of the erosional interval at the close of Boleo time, when the tops were planed off from the highest parts of the Boleo beds. Even the highest sediments, however, reflect to some extent the more notable topographic features that existed in the Comondú volcanics.

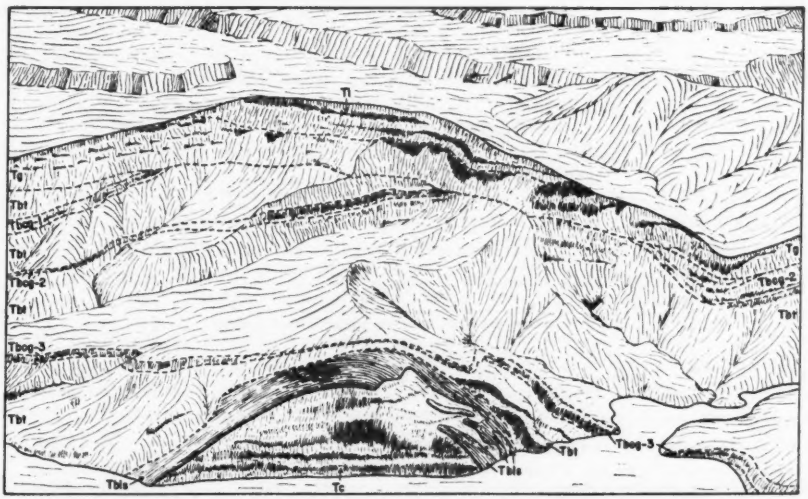
The original topography of the Comondú surface, as has been noted, had a relief of at least 450 meters around Cerro del Infierno. The structural relief of the overlying sediments in the same vicinity, that is, the change of elevation of a given bed in going over a buried hill or rising against an island, is as much as 200 meters for the basal marine limestone of the Boleo formation. For the top of conglomerate number 3, which normally lies about 80 meters above the limestone, the structural relief reaches 150 meters, and for conglomerate number 1, normally 105 meters above number 3, the structural relief is about 70 meters. This illustrates the decrease in structural effects of the original topography in successively higher beds.

EXAMPLE OF ANTICLINAL STRUCTURE OVER BURIED HILL

One of the best examples of an anticlinal structure over a buried hill may be seen near the Texcoco mine (Fig. 3, coordinates 3,000 N. and 3,000 W.), in a southerly branch of Arroyo del Boleo. At this place, uniquely enough and fortunately for the geologist, a modern arroyo has cut through the center of one of the buried hills of Comondú volcanics, clearly revealing its internal structure, original topographic surface, and the influence of this surface on the structure of the overlying sediments. This hill is shown in the accompanying sketch (Fig. 8) and the structure is indicated by a structure-contour map and structure sections in Figure 9. At the lefthand edge of the map in Figure 9 is shown the geologic distribution of the Comondú volcanics and the overlying cap of Boleo limestone which make up the buried hill (appearing in foreground of Figure 8). The remainder of the map shows structure contours drawn on top of Boleo conglomerate number 3. Structure contours at this horizon may be drawn with unusual de-

tail, since an ore bed resting on the conglomerate is honeycombed with mine workings.

The Comondú volcanic rocks that make up the buried hill are almost horizontal, having only a gentle easterly dip, and a fairly symmetrical hill with steep slopes on the north and south sides was eroded in these rocks. When the hill was submerged in the Gulf, the basal marine limestone of the Boleo formation was deposited over its entire surface, following all the topographic irregularities. As the limestone is resistant to erosion it has been preserved completely on the nor-

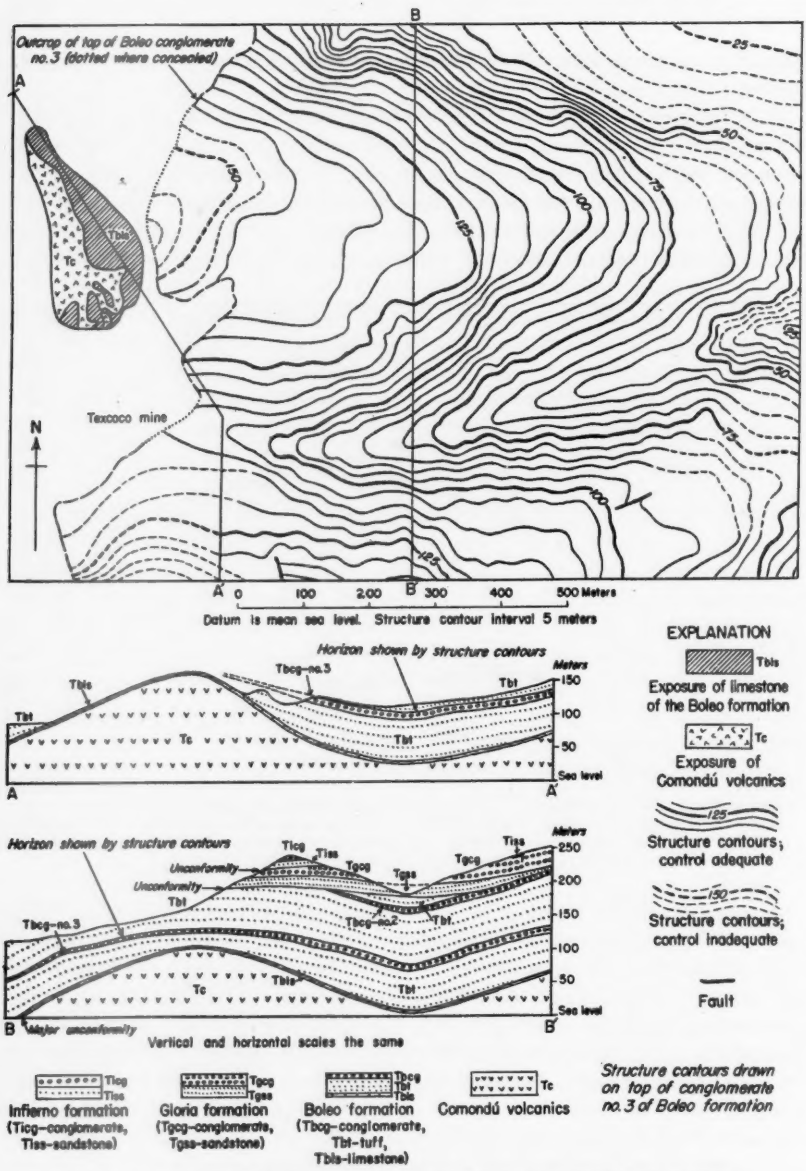


EXPLANATION: Tl=Infierno formation; Tg=Gloria formation; Tbt=tuff of the Boleo formation; Tbcg=conglomerate of the Boleo formation (numbered 1 to 3 from top to bottom); Tbls=limestone of the Boleo formation; Tc=Comondú volcanics. Drawn from an oblique aerial photograph, looking eastward toward Texcoco mine, south side of Arroyo del Boleo

SKETCH SHOWING STRUCTURE OVER A BURIED HILL

FIG. 8

thern dip slope, and in irregular patches on the south slope (Fig. 8). The limestone is horizontal on top of the hill, but dips from 23° to 33° on the north side and 30° to 38° on the south side. The south side of this hill had an irregular surface in detail, because of a difference in the resistance to erosion of the different volcanic layers. Depressions were filled in and knobs projected out into the limestone. At one point near the bottom of the arroyo is a small cliff about 2 meters high, to which the limestone adheres as if it were plastered to the surface. The succeeding tuff and conglomerate dip more gently than the limestone, dips of 27° having been recorded in the tuff and 20° in the overlying conglomerate (number 3). The sketch and structure sections indicate how the tuff beds below conglomerate number 3 wedge out against the sides of the hill, and how the conglomerate thins down as it approaches the top of the hill. Farther west along the continua-



STRUCTURE CONTOUR MAP AND STRUCTURE SECTIONS SHOWING PLUNGING ANTICLINE AND SYNCLINE FORMED OVER A BURIED HILL AND VALLEY
(Area south of Arroyo del Boleo, near Texcoco mine)

FIG. 9

tion of the same hill the conglomerate wedges out altogether. The dips of the post-Boleo beds are much gentler, partly because of the erosional unconformity at the base of the Gloria formation, which has resulted in removal of Boleo conglomerates 1 and 2 from the crest of the structure.

The structure-contour map (Fig. 9) shows the shape of the plunging anticline developed over the eastward continuation of the buried hill, as well as a plunging syncline adjoining it on the south, which was produced by deposition of sediments in an original valley, submerged to form a bay, carved in the Comondú volcanics. The eastward plunge of the anticline and syncline has probably been accentuated by later eastward tilting, but practically all the structural relief found along a north-south line (as in sections *AA'* and *BB'*, Fig. 9) can be attributed to initial structures. The minor crenulations in the structure contours resemble topographic irregularities.

EXAMPLE OF SYNCLINAL STRUCTURE IN BAY

A synclinal structure formed by initial deposition near the head of a bay is spectacularly exposed in a modern canyon, one kilometer west of the Texcoco mine. This seems to represent the inland continuation of the same syncline shown at the south end of Figures 8 and 9. A geologic and topographic map and structure sections revealing the synclinal structure are given in Figure 10. At this point the original valley carved in the Comondú volcanics was very steep and narrow, having all the aspects of a youthful canyon. When this canyon was submerged by the Gulf to form a bay the Boleo sediments were deposited only in the deepest part, and wedged out rapidly along the sides, particularly at the upper or western end. Cliffs of the Comondú volcanics that were probably never covered by the sea rise high above the Boleo sediments on either side, a relation due entirely to original topography, not to later faulting or deformation. This rather exceptional geologic situation, in which older rocks rise above younger, without deformation as a cause, is duplicated in many parts of the region.

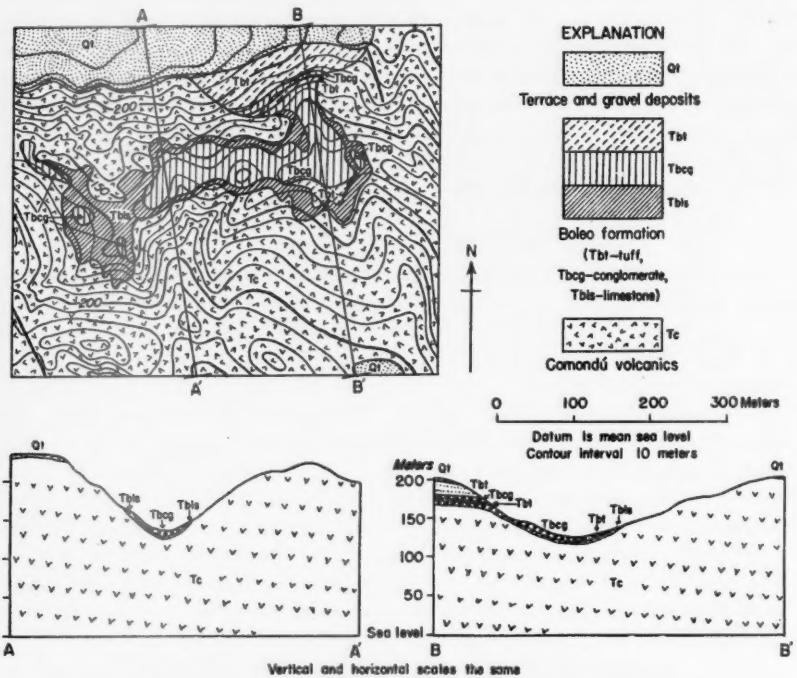
A sharp synclinal structure in the Boleo formation follows the axis of the valley, having steep dips on both the north and south sides (sections, Fig. 10). The Boleo sediments consist here of the basal limestone, an overlying conglomerate, and a thin intercalcated tuff. The conglomerate contains poorly sorted, rather angular débris, which was probably derived locally from material washed down from the sides of the canyon. The limestone itself is very impure here and contains much clastic material.

EXAMPLE OF STRUCTURE NEAR ISLAND

A good example of structure produced alongside an island of Comondú volcanics, showing how successive beds rise along the slope of the island and wedge out against it, is provided by Cerro de Juanita. The northeast slope of this Pliocene island is well exposed on the south side of Arroyo de Purgatorio, near the San Francisco shaft (which marks the junction of zero coordinates of Fig. 3).

A large-scale geologic and topographic map, structure section, and structure-contour map of this area are given in Figure 11.

The top of this hill, lying south of the map, reaches an altitude of 310 meters or 40 meters above the highest Pliocene sediments that were deposited on its flanks. The Comondú surface on the northeast side has an average slope of 30°,



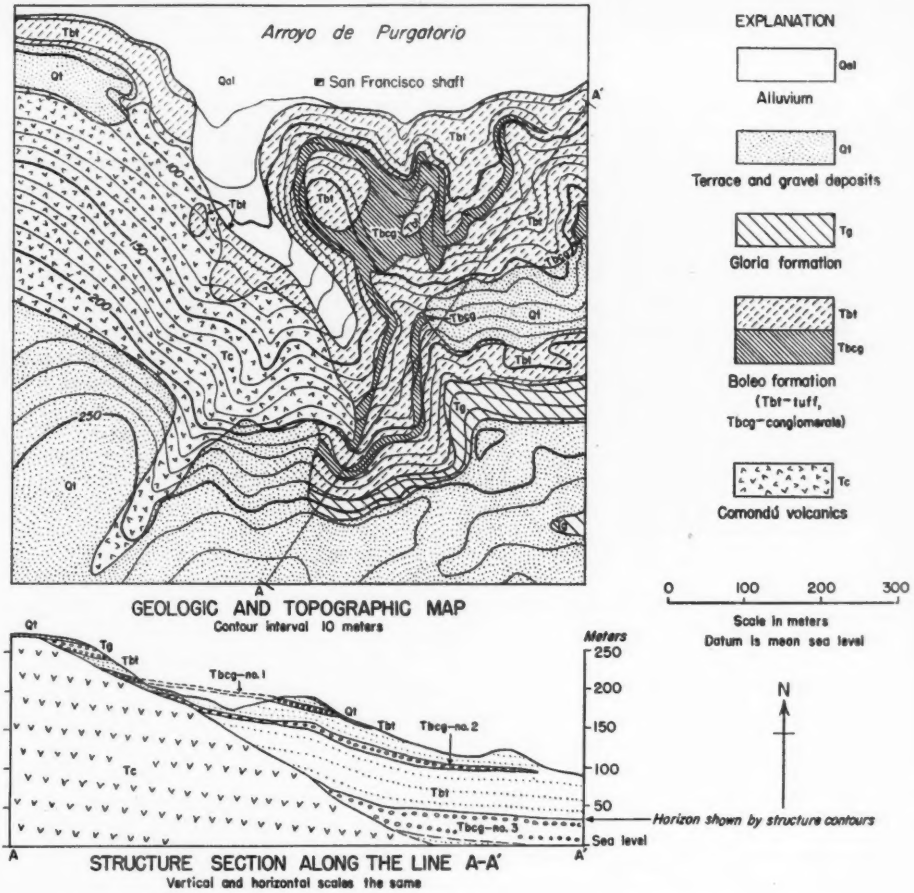
GEOLOGIC AND TOPOGRAPHIC MAP AND STRUCTURE SECTIONS SHOWING SYNCLINAL STRUCTURE FORMED IN A BAY

(Area in a branch of Arroyo del Boleo, one kilometer west of Texcoco mine)

FIG. 10

though the volcanic rocks themselves dip only 5° E., indicating that not a very large component of the overlying structure can be attributed to later tilting. Beds lying directly on the Comondú surface approach the 30° dip of the slope, but a short distance away the dip decreases to 20°, and 300 meters away from the surface the dip decreases to 3°.

The structure section in Figure 11 shows how the sediments cut out against the Comondú surface. In contrast to the buried hill previously described, the Boleo limestone here has disappeared somewhere below conglomerate number 3,



GEOLOGIC AND TOPOGRAPHIC MAP, STRUCTURE SECTION, AND STRUCTURE CONTOUR MAP SHOWING STRUCTURE FORMED NEAR AN ISLAND OF COMONDU VOLCANICS (Area on south side of Arroyo de Purgatorio, near San Francisco shaft)

FIG. 11

and is not shown on the section. The top of conglomerate number 3 wedges out at an altitude of 85 meters along the line of the section, though elsewhere it rises somewhat higher. Conglomerate number 2 rises as it approaches the Comondú surface, then rests directly on the surface for a distance of 60 meters before cutting out at an altitude of 200 meters above sea-level. The higher beds then successively wedge out against the side of the island.

This structure section is based on more than exceptionally numerous data. Conglomerate number 2 is well exposed throughout, and the structure of the top of conglomerate number 3 is known exactly from mine workings. The latter horizon is used for the structure-contour map in Figure 11. Only that part of the structure section below the top of conglomerate number 3 has been projected, although even here there is indirect evidence for the structure based on a near-by shaft.

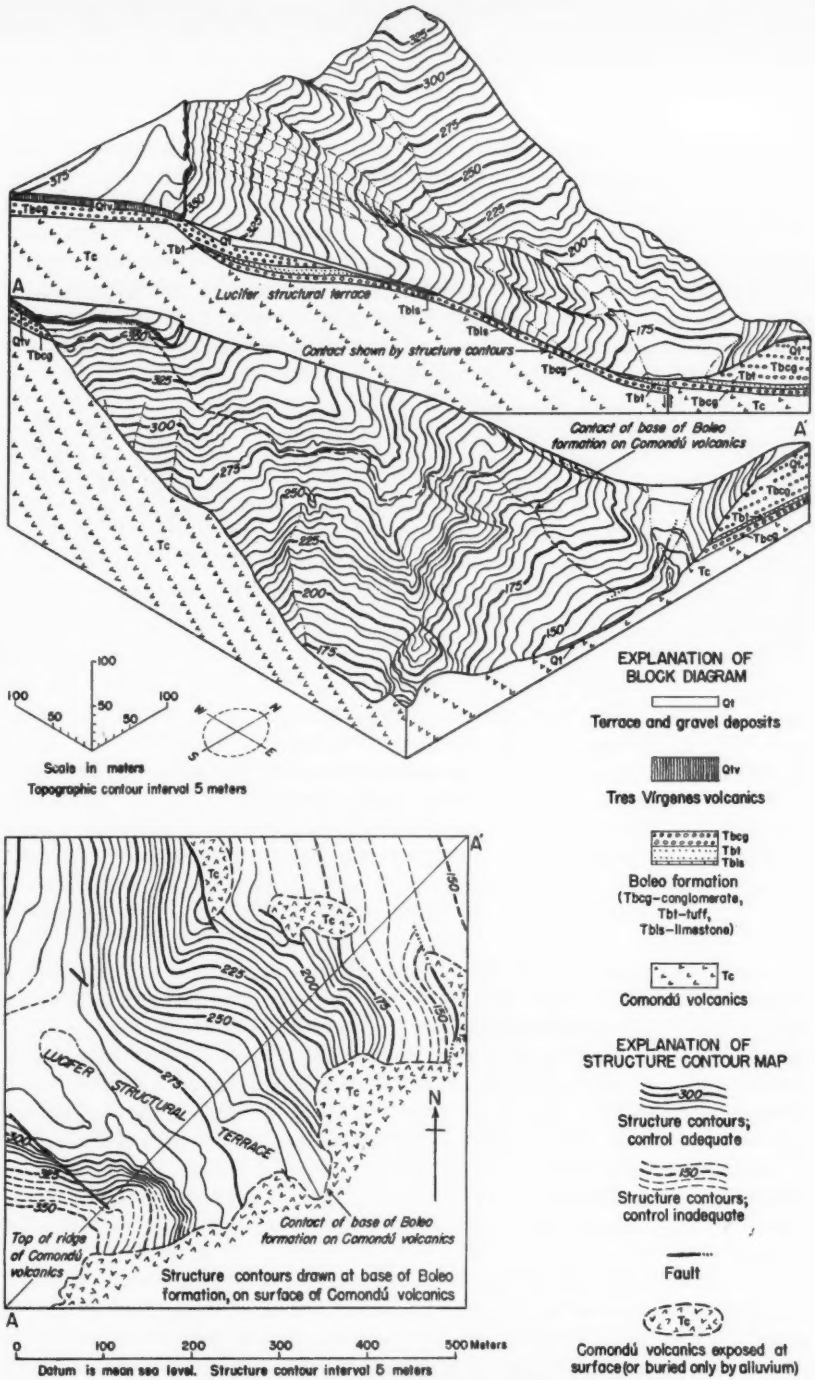
Similar structure against an island occurs on the east side of Cerro del Sombrero Montado, shown in section *DD'* of Figure 3, although this is not so well exposed as the example just described.

EXAMPLE OF STRUCTURE ADJACENT TO A RIDGE

Another example of structure produced by deposition against a steep surface of Comondú volcanic rocks, in this case a ridge that formed part of the Pliocene mainland, is well exposed at the south end of the Lucifer manganese mine (Fig. 3, coordinates 5,100 N. and 8,400 W.), in Arroyo del Infierno. A block diagram, showing topography and structure,[9] and a structure-contour map of the pre-Boleo surface of the Comondú volcanics are shown in Figure 12 (large-scale geologic maps and sections of this area are given in the report to be published on the Lucifer district). Here the original Comondú topographic surface rises from an altitude of 140 meters to an altitude of 350 meters within a horizontal distance of 470 meters. The dips have probably been accentuated by later tilting and faulting, but the fact of the original steeply inclined surface is demonstrated by the wedging out of the sediments against it. This was the surface of a ridge probably representing the extreme inland limit of the lower Pliocene shoreline, for no definitely marine beds have been found any farther inland along Arroyo del Infierno.

The Comondú surface here is mantled by a very coarse-grained non-marine basal conglomerate composed of angular fragments evidently derived from the ridge itself. Overlying the conglomerate is the thin marine limestone, dipping 25°–35°, which wedges out at an altitude of 270 meters above sea-level. Above the limestone is a 4-meter layer of tuff, containing the Lucifer manganese deposit near the top. The tuff wedges out at altitudes ranging from 285 meters at the south end of the outcrop to 320 meters above sea-level farther north. Only conglomerate, at least the inland part of which is probably non-marine, continues over the top of the ridge at an altitude of 350 meters.

[9] Because of the inherent distortion in such a block diagram the horizontal scale in the section AA' is slightly lengthened (by about 18 per cent) in relation to the vertical scale, which causes the dips to appear slightly more gentle than they actually are. The effect, however, is not great.


Lucifer structural terrace
Contact shown by structure contours
Contact of base of Boleo formation on Comondú volcanics
Tbcg
Qtv
Tbt
Tbls
Tc
Qt
A
A'
Scale in meters
Topographic contour interval 5 meters
EXPLANATION OF BLOCK DIAGRAM
Terrace and gravel deposits
Tres Vírgenes volcanics
Boleo formation (Tbcg–conglomerate, Tbt–tuff, Tbls–limestone)
Comondú volcanics
EXPLANATION OF STRUCTURE CONTOUR MAP
Structure contours; control adequate
Structure contours; control inadequate
Fault
Comondú volcanics exposed at surface (or buried only by alluvium)
LUCIFER STRUCTURAL TERRACE
Top of ridge of Comondú volcanics
Structure contours drawn at base of Boleo formation, on surface of Comondú volcanics
N
0 100 200 300 400 500 Meters
Datum is mean sea level. Structure contour interval 5 meters

BLOCK DIAGRAM AND STRUCTURE CONTOUR MAP SHOWING STRUCTURE ADJACENT TO A RIDGE OF COMONDU VOLCANICS
(Area around Lucifer mine, Arroyo del Infierno)

FIG. 12

A significant feature of the structure against this ridge is the presence of a structural terrace 100–150 meters wide, lying at altitudes of 270–295 meters above sea-level, which is labeled "Lucifer structural terrace" on the map (Fig. 12) as it contains the thickest part of the Lucifer manganese deposit. The terrace trends northwest, parallel with the surface of the Comondú ridge. The beds dip 30° below the terrace and then flatten to 5°–10°, becoming horizontal in places, before swinging up again to 30° and more against the Comondú surface. In the writer's opinion this structural terrace was developed over an original topographic bench (perhaps a wave-cut bench?) in the Comondú surface.

OTHER EXAMPLES

These examples of initial structures have been chosen because they are particularly well exposed, but they may be duplicated in many places. In the central part of section *AA'* of Figure 3, which is taken more or less at right angles to the direction of later tilting, practically all the structural relief shown is the result of initial topography. Most of the structural relief in section *BB'*, excepting the obvious faulting, is due to initial topography; and the structural effects of buried hills may be seen near the right-hand edges of sections *CC'* and *DD'*, which also show the effects of later tilting and faulting.

ORIGIN OF STRUCTURES

The evidence seems incontrovertible that the structure of at least the lowest beds, such as the basal marine limestone, which pass entirely over the tops of some of the buried hills, must be almost entirely a matter of initial dip. This must be true, for example, of the anticlines formed over hills in which the original topographic surface is well exposed, such as the one that has been described in detail and illustrated in Figures 8 and 9. If the assumption is made that the beds were originally flat and the dome was due to folding, then the topographic surface and underlying beds would also necessarily have been folded, or else the folded beds would have to show sliding or crumpling against the topographic surface, but neither event has occurred. In the example illustrated, in fact, the underlying beds are nearly flat whereas the overlying beds have steep to gentle dips following the contours of the topographic surface. The axes of the initial structures, furthermore, strike at various angles to the regional strike of the beds—a fact more compatible with a depositional than with a deformational origin. Initial dips rather than folding are further indicated by the fact that successively higher beds in the same formation have gentler dips and wedge out against the sides of the higher buried hills. As discussed later, the initial dips have been modified and augmented by later deformation (tilting, warping, and faulting), but the major structures that simulate folds are due to initial dips rather than to compressional folding.

The steep initial dips of the basal limestone were probably brought about by an actual coherence of the material to the surface of deposition. In such a manner initial dips may be as great as 90° in travertine deposits, according to Twenhofel (1939, p. 496), and it is known that lime oozes are now accumulating

on steep submarine slopes. The initial dips of the clastic deposits seem to lie within the limits of the subaqueous angle of repose as determined experimentally by various investigators. More than a century ago Rozet (1835) showed by experiments that normal sedimentary layers could be formed under water subjected to agitation on slopes as great as 30°; he also pointed out the likelihood that chemical deposits could be formed on even steeper slopes. Thoulet (1887, p. 47) gives 41° as the steepest slope on which sediments may stand, and De Lapparent (1906, p. 251) states that marine beds may be deposited with dips of as much as 35°. More recently M. B. Draper (cited by Twenhofel, 1932, pp. 604–05) found that the maximum subaqueous initial dip of sands ranges from 33° for fine, rounded grains to 43° for coarse, mixed angular and subangular grains; for medium-sized grains it ranges from 35° for rounded grains to 38° for angular grains. Initial dips attributed to clastic beds in the Santa Rosalía area locally reach 30° but more commonly range from 3° to 20°.

EFFECTS OF DIFFERENTIAL COMPACTION

Effects of differential compaction have probably been superimposed on the initial dips in the Santa Rosalía area, but they are believed to be of minor importance in comparison with the initial dips, and they can not be the sole cause of the structures as was apparently thought by Touwaide (1930, p. 125). Differential compaction, for example, could surely not have produced a structural relief of 200 meters in a basal limestone bed that is only 1–5 meters thick. Compaction is most effective in shales and other fine-grained sediments, and it could not be very great in the conglomerate or tuffaceous sandstone beds of the Boleo formation. Considerable compaction may have occurred in the clayey tuff beds, but these do not constitute a very large percentage of the stratigraphic section. The chief effects of differential compaction have probably been in accentuating the initial dips and particularly in transmitting the effects of the buried topography to the higher parts of the overlying section.

The quantitative aspects of differential compaction have been considered by Hedberg (1926, 1927, 1936), Rubey (1927), Athy (1930, 1934), Trask (1931), and others. Nevin and Sherrill (1929) showed by experiments the nature of folds that may be produced by differential compaction, and Nevin (1942, pp. 197–204) presents a good summary of the subject of differential compaction. Some other references to differential compaction as applied to Mid-Continent structures are cited in a succeeding section. It may be pointed out that the criteria for the recognition of compaction folds as noted by Nevin and Sherrill (1929), or supratenuous folds as they are later described by Nevin (1924, p. 46), such as thinning of sediments above the buried hill and increase of folding with depth, will apply equally well to initial structures whether or not differential compaction has occurred. Differential compaction, combined with solid flow of material away from the crests, as suggested by Nevin, will undoubtedly produce or accentuate a supratenuous fold, but the same type of fold could be produced by initial deposition alone. On the other hand, it would seem that an initial topography of

sufficient relief to produce a compaction fold would ordinarily have produced an appreciable original dip of the sediments before any compaction took place.

The initial structures along the Gulf of California somewhat resemble the structures produced by Nevin and Sherrill (1929) in their instructive experiments designed to illustrate the effects of differential compaction over buried hills. The main difference is that in the Gulf area the lowest beds pass entirely over the top of some of the buried hills, thus indicating the existence of initial dips, regardless of how much compaction may later have taken place. The experiments of Nevin and Sherrill, on the other hand, seem to have been conducted under such conditions that the beds were originally deposited in a horizontal position, without any appreciable initial dip. While this admirably served the purpose of the experiments, which was to show the possible effects of differential compaction alone, it does not necessarily follow that most of the structure found over a buried hill (excluding later deformational effects) is ordinarily due to differential compaction rather than to original dip. In their experiments Nevin and Sherrill settled clay in a tank having a flat bottom, surmounted by Plaster of Paris hills, and agitated the water sufficiently to prevent the sediment from piling up over the hill-tops thus laying down level markers. The experiments thus evidently apply to an area of deposition exclusively of clay, subjected to strong wave action. As will be shown in the succeeding section, these particular conditions are least conducive to the formation of initial dips on steep slopes, whereas certain other environments are much more favorable to their formation.

Actually the processes of differential compaction and deposition with initial dip doubtless proceed hand in hand, and it would seem to be difficult, for any particular layer situated well above the buried topography, to determine the exact components of each. Wherever the buried topographic surface itself is exposed, however, it should generally be possible to observe whether at least the lowest beds were deposited with an initial dip parallel with the surface, or whether they were deposited in a horizontal position and butt against the surface. Most deposits probably fall somewhere between these extremes. As there is a tendency for thicker deposition in the basins and thinner deposition over the hills, each succeeding bed will depart a little farther from the angle of the original slope and approach a little closer to horizontality. This process would doubtless continue until nearly horizontal beds might be deposited at some unknown height above the buried topography. If however there are any highly compactible beds in the section, greater settling over the basins would tend to perpetuate the general shape of the original topography and permit the irregular surface of deposition to extend farther upward than would be possible through the process of initial deposition alone.

FACTORS CONTROLLING FORMATION OF INITIAL DIPS

The more important factors controlling the formation of initial dips in marine beds are probably the following: (1) the nature of the sediments, (2) the degree of agitation of the water, (3) the rate of deposition of the sediments, (4) the rapidity of submergence, and (5) the nature of the original topography on which

deposition takes place. Clays are least likely to accumulate on steep slopes and are most easily distributed by wave and current action. In other clastic sediments the coarser and more angular grains tend to stand on the steepest subaqueous slopes. Calcareous deposits, and probably certain other chemical sediments as well, may evidently cling to steep surfaces through coherence and early induration of the material, as indicated by the steep dips found along coral reefs. Strong agitation of the water will of course limit deposition on steep slopes by removing and spreading the material. The degree of agitation of the water would depend upon such factors as configuration of the coast, size of the body of water, distance from shore, depth of water, nature of currents, and various oceanographic conditions.

Rapid deposition of sediments will tend to restrict their redistribution by wave or current action and favor the development of initial dips. The rapid submergence of a coastline would probably promote the formation of initial structures, in that sediments could be deposited simultaneously over the higher and lower parts of the topography, and a considerable thickness of sediments could accumulate before any "profile of equilibrium" would be established. The nature of the original topography is of course the primary factor that will determine the degree of initial dip that may develop. Provided that agitation of the water is not too great, it would seem that sediments could accumulate on any slope up to that of the subaqueous angle of repose for the particular type of material being deposited. On steeper slopes, however, the sediments might not be able to accumulate so that initial dips would be inhibited. For example, Dake and Bridge (1932, p. 646) found that on pre-Cambrian hills of the Ozarks the dips of the overlying beds approximate the slope of the hills, unless these exceed 35°. On steeper hillsides the abutting sediments show little or no dip, seemingly because the sediments could not accumulate on the steeper slopes.

Most of the conditions in the Santa Rosalía area during the Pliocene were evidently favorable to the accumulation of sediments on steep slopes without much redistribution. An irregular topography was evidently submerged sufficiently rapidly so that the same layer could be deposited simultaneously over the tops of the smaller buried hills and in the adjoining buried valleys. The basal deposit was calcareous, so that coherence of the material enabled it to cling to steep slopes. This was followed by the rapid deposition of dominantly coarse clastic sediments, accompanied probably by a minimum of wave action. In the Gulf of California wave action is generally less effective than in the open ocean, and in the Santa Rosalía area during the Pliocene it was further restricted by protecting islands and embayments. It is clear, at any rate, that agitation of the water in the area described was not sufficient to prevent the sediments from accumulating along the steep slopes of the buried topography.[10]

[10] Some of the deposits forming the initial structures described in the Santa Rosalía area may be non-marine, as has been discussed in connection with the origin of the Boleo formation, and to these deposits the question of agitation of the water would not apply. At least the lower part of the section, however, including the steeply dipping basal limestone, is definitely marine as shown by the presence of marine fossils.

INITIAL STRUCTURES DESCRIBED IN OTHER REGIONS

Structures due mainly to initial dips in marine beds seem to have been infrequently described in other regions, although they are probably common in terrestrial and volcanic deposits. Enough data have been presented from scattered localities, however, to indicate that steeply dipping marine sediments not only can but have been formed on initial slopes, and that steep initial dips are particularly prevalent in limestones. Some of the earlier references are to steep initial dips on the flanks of coral reefs. Chamberlin (1877, p. 366), in describing the Silurian reefs of Wisconsin, reports dips as high as 54° close to the reefs, although Grabau (1903, pp. 341–42) states that dips of 28°-34° are more common, decreasing rapidly to 18° away from the reefs. Grabau (1903, p. 339) further describes the Middle Devonian reefs of Michigan, around which clastic beds show dips of 28° near the reef, falling rapidly to 14° and then more gradually to 2°, which is the normal dip of the strata. Cumings and Shrock (1926, 1928) describe numerous Silurian reefs in Indiana, in which the inclined beds of the reef flank or fore-reef, leaning against the massive core, show dips in various localities of 30°–65°. Permian reef beds in the Guadalupe Mountains of West Texas and New Mexico dip 10°–30° as they rise away from the adjoining basins, most of the dip having been interpreted as original, though somewhat modified by later tilting (King, 1942, pp. 636–40).

Folds were attributed in part to initial deposition by Shaw and Munn (1911, p. 40) who, in a description of the Foxburg Quadrangle, Pennsylvania, state that the irregular broad folds encountered there are a product "(1) of irregularities of the surface upon which each layer was deposited; (2) differential settling; (3) warping at various times since deposit." In a later paper Shaw (1918) describes a few localities in which initial synclines were thought to have been formed in basins in Pennsylvania. He pointed out in the same paper that calcareous deposits seem to become indurated more promptly than those of arenaceous or argillaceous make-up (a probable factor in permitting steeper initial dips to form in limestones than in clastic rocks).

Initial quaquaversal dips above rounded hills and knolls on a pre-Cambrian surface were noted by Mather (1918), who described several examples in the Ordovician limestones of eastern Ontario. A well known example of former islands of pre-Cambrian rocks surrounded by Paleozoic sediments is provided in the Baraboo area of Wisconsin, and the term "baraboo" has sometimes been applied elsewhere to hills or islands that were once buried by sediments and later exposed to erosion (Mansfield, 1908, p. 291; Powers, 1931, p. 118). Cambrian sediments have initial dips of as much as 15° or more adjacent to the Baraboo islands, according to Wanenmacher *et al.* (1934, p. 3). Evidence for a 5° depositional dip in a Silurian shaly dolomite overlying a buried Ordovician hill near Joliet, Illinois, has been given by Fisher (1938). Local structures in the Permian redbeds of the Wichita Mountains of Oklahoma were attributed to initial dips by Taff (1904, p. 72), and evidence for gentle initial dips on the Gulf Coastal

Plain of Louisiana and Texas has been given by L. S. Brown (1934, pp. 1249–67).

Twenhofel (1932, pp. 604–06) discusses the conditions under which steep initial dips are likely to form, and cites several examples in both recent and ancient sediments. An extensive discussion of initial dips in recent sediments is given by Walther (1894, pp. 633–36), who reports several examples of steep dips along coral reefs, on delta fronts, on volcanic islands, and along rugged shorelines. According to Studer (1836, p. 699) beds in a delta in Lake Lungern, Switzerland, are inclined as much as 35°, and Thoulet (1887, p. 54) states that a delta in Lake Brienz has a slope of as much as 30°. Forchhammer (1841, p. 24) noted on the coast of Denmark sandy beaches with slopes of 6°–14° and pebbly beaches with slopes as great as 25°. Thompson (1937, pp. 739–40), who made 1200 measurements of slopes of beach surfaces and laminae in the western United States, found that 57 per cent of the laminae in lower foreshores had slopes of 16° or more, as compared with 3 per cent of the laminae in upper foreshores. He also noted an average maximum slope of 28° in 200 measurements of foreset slopes in deltas and sand bars of tidal pools. The burial of islands in Great Salt Lake, producing anticlinal structures in the sediments, has been described by Eardley (1938, pp. 1408–11). Sedimentation on an irregular buried topography in the Gulf of Maine is illustrated in numerous fathogram profiles given by Murray (1947). He states that in some places, where a dual bottom suggests sedimentation, the slope of the upper reflecting surface (presumably of the sediments) may range from 20 to 70 per cent (11°–35°). It seems likely that these angles represent the degree of initial dips in the sediments.

The examples of steep initial dip in recent sediments cited above have been emphasized because of their bearing on the structures under discussion, but it should not be implied that marine depositional slopes in general are as steep as this. On the contrary, the slopes in front of large deltas on the continental shelf average only 0.7 per cent (0° 25′), according to Shepard (1941, p. 1873), and the average slope of the steepest part of 500 profiles which he constructed of the continental slope off all shores of the world is 8.6 per cent (4° 55′).

The well known domes formed over buried hills in the Mid-Continent region, particularly in Kansas and Oklahoma, have attracted much attention, due to their importance in petroleum geology. The origin of these domes has been the subject of considerable controversy, and a discussion will not be entered into here of all the factors that may be involved, including deformational effects. The theory that much of the structure of these domes is a result of differential compaction of the sediments over buried topography became very widespread in the decade beginning in 1920, through papers by Blackwelder (1920), Mehl (1920), Powers (1920, p. 121, 1922, 1925), Moore (1920, p. 258), Monnett (1922,[11] 1927), Teas (1923),[11] Rubey (1923, pp. 51–54), Ley (1924), and Rubey and Bass

[11] The papers by Monnett (1922) and Teas (1923) discuss a variant of the theory, that some folds may be caused by differential compaction over and around sand lenses. Further contributions on this subject have been given by Shrock and Malott (1929), and Rich (1938).

(1925, pp. 72–86), among others. Powers (1926) extended the theory to several possible examples of buried hills in Persia, Egypt, and the Mexican southern oil fields. More recently the theory has been applied to fields in Ontario (Harkness, 1935, p. 72) and northern Texas (A. B. Brown, 1943, pp. 36–37). Foley (1927), R. W. Brown (1928), Cheney (1929, p. 587), McCoy (1934, pp. 618–24), and various others, however, have minimized the effects of differential compaction in producing Mid-Continent structures, and Powers seems to assign it much less importance at a later date (1931) than in his earlier papers.

The possible role of original dips *per se* in producing some of these Mid-Continent structures over buried hills seems not to have been emphasized until more recently, although an early suggestion of initial dips as well as compaction was made by Merritt (1920). Thomas (1929), in considering folds of Pennsylvanian and Permian strata over part of the Nemaha Mountains (Granite Ridge) of Kansas, concluded that they were due in part to differential settling and in part to depositional dip over anticlinal buried hills. Landes and Ockerman (1933) concluded that the pronounced domes in Lincoln and Mitchell counties, Kansas, owed their steep dips to deposition conformable with the surface of buried hills. Walters (1946), in a study of buried pre-Cambrian hills in Barton County, Kansas, concluded that the quaquaversal dips of the Cambro-Ordovician beds over the hills are depositional features, or initial dips.

Probably the best exposed initial structures so far described in the United States are those of the central Ozark region, in the St. Francois Mountains of southeast Missouri, as described by Dake and Bridge (1932; see also Bridge and Dake, 1929, and Bridge, 1930, pp. 151–68). In that region are exposed many hills and ridges on a pre-Cambrian land surface that had an average relief of about 1500 feet when invaded by the Cambrian seas. Dips as steep as 30° were noted in limestones adjacent to the hills, although the dips in clastic sediments are less, averaging 10°–15° in basal conglomerate and 4°–5° in sandstones. The structural relief for particular beds amounted to 500–800 feet—figures comparable with the maximum amounts found near Santa Rosalía. A dendritic valley system was found in the pre-Cambrian igneous rocks, the valley floors being occupied by Cambrian sediments which, in all places, dip toward the axis of the valley from both sides.

Dake and Bridge (1932, pp. 639–47) discuss at some length the possibilities that have been suggested for the origin of dips around buried hills, considering (1) intrusive doming; (2) isostatic adjustment; (3) recurrent vertical uplifts; (4) lateral crustal deformation; (5) compacting of the sediments; (6) settling resulting from solution of limestone; and (7) initial or depositional dips. They conclude that the dips observed in the Ozark region are almost entirely initial dips, although they state that compacting may have in some degree accentuated the observed dips. All the possibilities suggested here except for initial dips and compacting (crustal deformation having acted only as a modifying force) may readily be dismissed as possible agencies in producing the steep dips around buried hills in the Santa Rosalía area.

Similar structures to those herein described are probably widespread around the edges of the Gulf of California. They must be forming at the present time in the Gulf, considering the rough and irregular character of its bottom and sides. Probably the reason initial structures have not been described more frequently is that nearly all of our stratigraphic and structural studies have been made on sediments deposited on continental shelves or in shallow epicontinental seas, in which the relief has been slight and broad smooth surfaces have been the rule. It would seem that in any submerged region of high relief, containing an irregular surface with headlands and bays, initial dips would necessarily be developed in the overlying sediments. In any highly deformed region, of course, such as the Coast Ranges of California, it would be difficult to differentiate the effects of the initial dips from the structures produced by later deformation.

STRUCTURES PRODUCED BY DEFORMATION

Superimposed upon the initial structures just described are the effects of regional deformation, including tilting, warping, and faulting. The main effects of this deformation have been to modify and accentuate the original dips. Where the initial dip is in the same direction as the later tilting it may be difficult to separate the components of the two, but where the initial dip is at right angles to the direction of tilting the two types of structure may generally be recognized. Effects of tilting and faulting superimposed on initial dips are shown by sections *BB'*, *CC'*, and *DD'* of Figure 3.

The general regional dip of the Boleo formation, in the areas away from the buried hills, ranges from 3° to 10° E. or NE., although it locally steepens to 20° and elsewhere becomes nearly horizontal. Steepening near faults is common, as a result of drag. Although warping has occurred, very few if any true folds were seen other than those produced by original topography.

Recent northeastward tilting has lifted the late Pliocene and Pleistocene marine beds to elevations of 250 meters above sea-level at distances of about 4 kilometers southwest of the present shoreline over the central part of the area mapped. The tilting was greatest in the northwest part of the area, in Arroyo de las Palmas, where the marine beds attain an altitude of 340 meters, and it gradually subsided southeastward so that in the San Bruno plain, south of Santa Rosalía, there has apparently been no substantial uplift since the Pleistocene. Near Arroyo de Santa Agueda there seems to have been tilting or downwarping toward the southeast. Evidence from unconformities indicates that tilting probably occurred as many as four times after deposition of the Boleo formation—at the close of the lower Pliocene, middle Pliocene, upper Pliocene, and Pleistocene. The most recent tilting and uplift took place in stages, as evidenced by prominent marine terraces consisting of at least two main levels.

In connection with the recent uplifts it should be mentioned that Wittich (1912, 1920) has described the evidence in various localities for recent uplifts along the Pacific Coast of Baja California, and reports one locality on the main divide of the peninsula at San Borja, about 115 kilometers northwest of Santa

Gertrudis (Figure 1), where supposedly recent shells ("subfossils") occur at an altitude of 1052 meters above sea-level. From this he concluded that waters from the Pacific extended continuously across the peninsula to the Gulf in various places within recent geologic time. Without affirming or denying this possibility it may be stated that the recent uplifts of marine beds in the area mapped near Santa Rosalía have not exceeded 340 meters above sea-level and are generally less, and that the evidence is contrary to the idea that the sea may have extended entirely across the peninsula in this particular area.

The major faults affecting the region are westward-dipping normal faults having displacements most commonly of about 10 meters and which rarely exceed 60 meters. There are also a number of eastward-dipping normal faults which generally have even smaller displacements. Most of the faults trend north-northwest, more or less parallel with the general regional strike of the beds, though a very few faults are parallel with the direction of dip of the beds. The faults generally die out within short distances along the strike, and their place is commonly taken by others arranged *en échelon*. The general effects of the faulting have been to steepen the regional easterly dip of the beds, and to produce a successive repetition of the beds. The pattern of faulting is best illustrated by section *CC'* of Figure 3, in which the offsets and dips of most of the faults shown have been revealed in mine workings.

The major faulting (aside from the pre-Boleo faulting described previously) probably occurred near the close of the Pliocene, although in a few places the Pleistocene beds are cut by faults, indicating a renewal or continuation of activity. Even the Pleistocene or Recent lava flows are offset by some very small faults, indicating that faulting occurred within fairly recent time, but the faults of greatest displacement appear to antedate the Pleistocene beds.

SUMMARY OF GEOLOGICAL HISTORY

The region is underlain by a plutonic basement, possibly of Cretaceous age, though known definitely only as pre-Tertiary. Cretaceous, Eocene, Oligocene (?), and lower Miocene marine sediments were deposited on the west coast of Baja California, but do not extend to the east coast near Santa Rosalía.

During the middle or late Miocene, volcanic highlands occupied the present site of the Gulf of California. Thick volcanic rocks (Comondú), derived from the east, formed near the present shore of the Gulf, giving way westward to terrestrial sediments. Probably during the late Miocene, these rocks were deformed near the present Gulf shore by normal faulting, forming a series of eastward-tilted blocks. The main part of the peninsula was probably tilted westward at this time. This was accompanied by profound sinking of the former highlands to the east, perhaps by downfaulting.

Following the late Miocene deformation, erosion had attained a stage of only youth or early maturity when the eastern margin of the peninsula was invaded by the Gulf of California. The result was a rugged, irregular shoreline of high relief, characterized by headlands, bays, islands, and buried hills. The Gulf ex-

tended 6–10 kilometers farther inland than at present, but receded in successive epochs.

Early Pliocene deposition was initiated by a non-marine basal conglomerate, deposited locally around the steeper hills. As the Gulf advanced, a basal marine limestone was deposited, covering the tops of the smaller hills and wedging out around the islands. Gypsum was then deposited in local areas, perhaps indicating the development of lagoonal conditions. Then followed the deposition of thick alternating tuffs and conglomerates, probably partly marine and partly non-marine. The conglomerate lenses suggest deltaic deposits grading seaward into sandstone, but the normal sedimentation was interrupted at least five times by explosive volcanic eruptions which formed the tuffs. The shoreline receded seaward as the deposits accumulated. The sediments show initial structures developed over the original topography, anticlinal structures having formed over hills and synclinal structures over valleys. The structural relief was greatest in the basal beds and diminished in the successively younger beds.

At the close of the early Pliocene deposition, the landward area was uplifted by tilting, and some erosion of the higher members of the Boleo formation occurred. The unconformity seems to die out seaward, where deposition may have continued more or less uninterruptedly.

Marine near-shore deposition proceeded in the middle Pliocene, forming a local basal conglomerate, a marine sandstone wedging out inland, and a conglomerate thinning down seaward, probably grading inland into a non-marine facies. The middle Pliocene deposition was locally terminated by uplift, tilting, and erosion, which apparently affected only parts of the area.

Marine deposition continued in the late Pliocene, forming a marine sandstone that wedged out landward, and a conglomerate that thinned down seaward and graded inland into non-marine beds. Locally a prominent unconformity indicates uplift, tilting, and erosion following the late Pliocene deposition. Faulting probably took place at this time, although it continued or recurred in Pleistocene or Recent time.

Thin marine deposits of sandstone and conglomerate, accompanied by a non-marine inland facies, were formed during the Pleistocene. The Pleistocene marine beds were uplifted as much as 340 meters above sea-level. The uplift occurred in at least three main stages, indicated by two well defined intermediate terrace levels. Erosion followed, which is still in a stage of youth, as substantial areas of undissected mesas lie between the arroyos.

Volcanic activity, starting perhaps in the Pleistocene but continuing into historic time, built the Tres Vírgenes and other volcanoes and spread pumice deposits and lava flows over the mesas northwest of Santa Rosalía.

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GAS FOR THE FUTURE[1]

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ABSTRACT

The growth of sales of natural gas has been one of the outstanding industrial developments of the United States during the past 25 years. During this period, the estimated reserves of natural gas have been increasing at an even more rapid rate. Pipe-line projects approved by the Federal Power Commission indicate a sudden increase in the use of natural gas for the period just ahead. To maintain the comfortable ratio of gas reserves to sales enjoyed by the industry in the past, important additional reserves will have to be discovered.

The large sedimentary basins, remnants of more extensive areas of deposition, are the loci of geological conditions necessary for important accumulations of oil and gas. In the successful exploration of these basins, the role of the geologist in interpreting well data for the correlation of deeply buried strata far from outcrop and in directing exploration to areas of favorable depositional facies of potential reservoir beds will be of the utmost importance.

The status of exploration and prospects for further discoveries of 33 important basin areas in the United States are briefly discussed in the paper. On the basis of available data, of those basins which are adequately explored so that geologic conditions are fairly well established, the Anadarko, Midland, and Gulf embayments offer the greatest promise of discovery of substantial reserves. Of these, the Gulf embayment, defined as including the area from beyond the Rio Grande to the east side of the Mississippi delta and including the tidelands area, is believed to have the greatest prospects. Accordingly, it appears that in the future, as at the present time, more than half of the gas reserves of the United States will be in fields situated in Texas.

INTRODUCTION

The steady growth of sales of natural gas has been one of the outstanding industrial developments of the United States in the past 25 years. During this period there has been an even more rapid increase in the proved reserves of natural gas as estimated by various qualified experts. Because present indications are that in the near future sales expansion will be even more rapid, it is appropriate to pause and inquire where gas for these enlarged markets will be produced. Is there likely to be an adequate supply for to-morrow's markets?

Oil and gas occur in similar geologic environments; in fact, it is not possible to predict in advance of drilling which type of hydrocarbon is more likely to be found. To indicate the problem with which the natural gas industry is faced, the following discussion will touch briefly on gas sales, gas reserves, and the general geologic principles used in exploratory activities. Its principal purpose is to indicate the major areas in which further important discoveries are likely to be made and the nature of the geologic problems to be solved in their exploration. General conclusions regarding the prospects for discovery as indicated by available data are presented in brief summary form.

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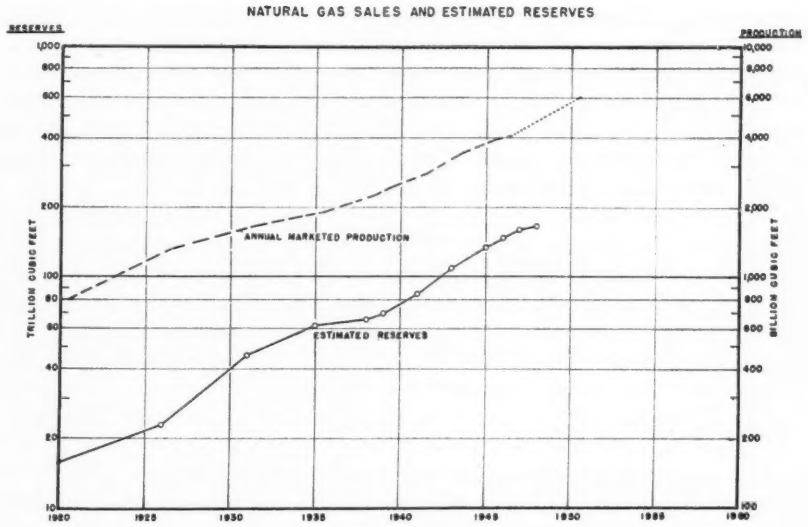

FIG. 1

GAS SALES AND RESERVES

Data on the sales and estimated reserves of natural gas are presented in Figure 1. The significant trends shown by this chart are the continued increase in sales, the more rapid percentage increase in estimated reserves, and an accelerated increase in sales anticipated for the near future.

The gas volumes on this chart are plotted on a logarithmic scale so that lines having a uniform slope indicate a uniform per cent of annual change. In the past decade the marketed production has increased at a fairly uniform rate, which is about 8 per cent per annum. The projection of marketed production to 1950 is based on estimated present sales, plus the use of new transportation facilities approved by the Federal Power Commission.

The estimates of natural-gas reserves shown on the chart are believed to be the best available, points on the line representing the date and amount of individual estimates. It is noteworthy that over most of the period covered by the chart, the rising slope of the line showing estimated reserves is steeper than that of the annual marketed production, thus indicating an improving reserve position during the period considered. If this relationship is to be maintained through 1950, additions to reserves will have to be at a higher rate than in the past. The most recent estimates, however, suggest a reduction in the rate of additions to gas reserves although, as shown by the chart, new reserves proven during 1947 were substantially in excess of production.

Of particular interest is the general geographic distribution of the presently known reserves. According to the American Gas Association estimates, approximately 54 per cent of the total natural gas reserves are in fields in Texas. Other estimates show that less than one-third of this Texas reserve is in the great Panhandle field. Of the other states, only Louisiana has more than 10 per cent of the total. The combined reserves of the leading five states are 90 per cent of the total for the country, as shown in Table I.

TABLE I

ESTIMATED PROVED NATURAL-GAS RESERVES
December 31, 1947, American Gas Association

State	*Est. Reserves (Trillion Cubic Feet)**	*Percentage of U.S.*
California	10.2	6.1
Kansas	14.6	8.8
Louisiana	23.5	14.2
Oklahoma	11.4	6.9
Texas	90.0	54.2
Total five states	149.7	90.2
Others	16.2	9.8
Grand total	165.9	100.0

* Measurement pressure base, 14.65 pounds per square inch.

From the foregoing, we see that there is a marked geographic concentration of important gas reserves, mainly at a considerable distance from the previously established centers of industry and population.

GEOLOGIC FACTORS IN NATURAL-GAS ACCUMULATION

Three rather obvious and well known geologic conditions are required for the accumulation of commercial natural-gas reserves as follows: (1) a source material; (2) reservoir rocks which can accumulate important amounts of gas and permit it to flow to wells for production at satisfactory rates; and (3) structural conditions, including an impervious cover which retains a localized gas accumulation in the reservoir, preventing its escape.

As is also well known, geologists, in their research, have found that certain areas of the earth have had a tendency to sink during important geologic eras. In general, sands, muds, and other materials have been poured into these basin areas over long periods of time with the result that even after compaction under the pressure of deep burial, the thickness of the indurated sediments may reach a total of many thousands of feet. Conditions under which these processes took place have generally resulted in the accumulation of source material for oil and gas and of suitable reservoir rocks. In many cases, periods of deposition were interrupted or terminated by mountain building forces resulting in uplift, folding, and faulting of large parts of the sedimentary basin. Thus, in a sedimentary

basin, all of the fundamental conditions required for the accumulation of oil and gas into commercial deposits are potentially present.

In most sedimentary basins, the high structures were subjected to erosion, which tended to plane them off to a more level surface. In many basins deposition was resumed at a later time so that new sediments covered the older structural features with flat strata which reflect these structures poorly or not at all. The erosion following deposition removed parts of the older sediments, in some areas permitting the escape of oil and gas, and in others entirely removing the petroliferous strata. Thus, at the present time, the geologist and oil and gas producer are engaged in exploration to discover remnants of the original oil and gas accumulation, often trying to find them below a mask of later deposits.

Earlier exploration and field development took place along important structural anticlines or ridges which were overlain by relatively thin sedimentary deposits, on structures near the margins of sedimentary basins, and on the flanks of salt domes having a surface expression. As examples of fields exploited during this era of development, mention may be made of the Cincinnati arch of Ohio-Indiana, the southeastern Illinois fields, the Barton arch of central Kansas, the Sabine uplift of northwestern Louisiana, the Bend arch of north-central Texas, the buried Amarillo mountain range underlying the Texas Panhandle field, and the Nemaha ridge of eastern Oklahoma which extends from its southern end near Oklahoma City into southeastern Nebraska. The greatest depth of potentially producing zones in these areas is modest and areas of known favorable local structure have largely been explored down to the so-called basement rocks. Although local structures on which oil and gas fields of importance in local use are likely to be discovered in such areas for some time to come, the reserves of such future fields are probably neither large individually nor likely to be of national importance in the aggregate.

MODERN EXPLORATION TRENDS

As a result of improved exploratory technique and greater drilling depth capacity, the deeper portions of sedimentary basins have been explored with considerable success during the past decade. Important refinements in geophysical methods and improvements in well logging and in interpretation of subsurface data have opened many of the basin areas to exploration under conditions assuring a reasonable chance of finding oil and gas deposits, if present. Greater drilling capacity now enables operators to undertake such exploration even though the objective is expected at depths of 15,000 feet or more.

Recent exploration in the Big Horn basin is typical of opportunity for discovery in the more promising basins. Since it also illustrates the geologic conditions described previously and the solution of some exploration problems by geophysics, it is described briefly.

The Big Horn basin of northwestern Wyoming (Fig. 2, No. 8) is of modest size. It has been known as an oil- and gas-producing area for more than 30 years.

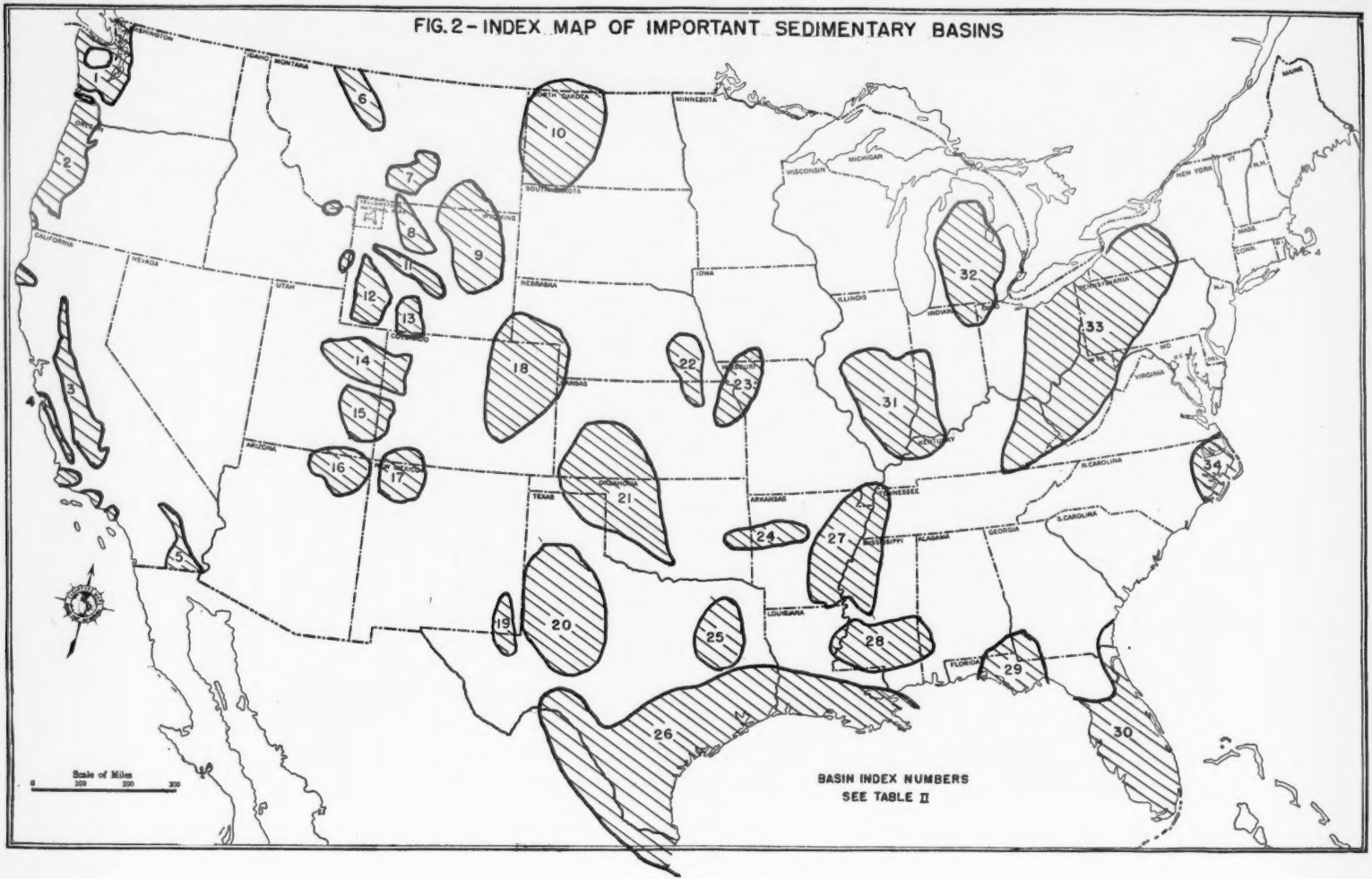
FIG. 2 - INDEX MAP OF IMPORTANT SEDIMENTARY BASINS
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WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
S. CAROLINA
N. CAROLINA
VIRGINIA
W. VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE
VT.
N.H.
MASS.
CONN.
R.I.
N.J.
MD.
DEL.
Scale of Miles
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100
200
300
BASIN INDEX NUMBERS
SEE TABLE II

FIG. 2

Situated between mountain ranges, it is a topographic as well as structural basin. The basin is of particular interest because of the pronounced and readily mapable local structures situated around its present margins, and of the results of recent deep exploration in the central area where the structure of the producing formations is hidden by a cover of strata deposited subsequent to the principal deformation. Published data provided the basis for the accompanying cross section of the southern part of the basin (Fig. 3), which shows the relationship of a recently discovered producing structure to the previously known structures.

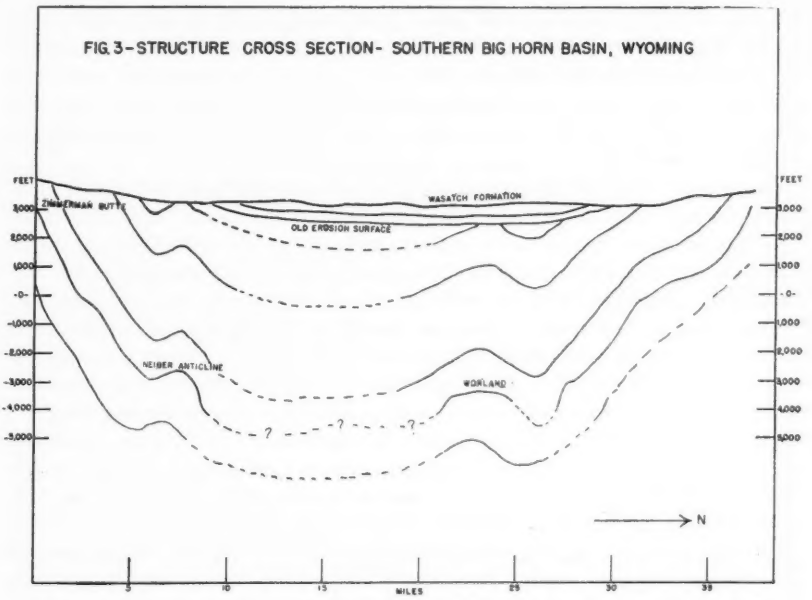

FIG. 3

The salient features of the geology of this area are indicated by the cross section. First is the location of the Worland dome deep within the basin structure, where drilling depths exceed greatly those of fields located near the margins of the basin. Second is the cover of flat beds deposited after the folding and erosion of this structure. Third is the sharp dips of the structure which result in an area of production greatly elongate in the direction of the axis of folding. The improved applications of geophysics in this field have permitted a program of successful exploratory step-out drilling.

ROLE OF GEOLOGIST IN MODERN EXPLORATION

Some of the geologic aspects of modern exploration merit passing consideration, for the geophysical success in finding the producing structure just described

does not mean that geologic studies of the highest quality have been superceded by a superior science. On the contrary, good interpretation of geologic conditions, including geologic structure, is essential if oil and gas are to continue to be available in abundance and at reasonable cost. Some of the more obvious reasons for this statement follow.

As indicated earlier, most of the present geologic basin areas are remnants of the ancient embayments in which oil and gas source material and reservoir rocks accumulated. In the majority of cases, the location of the present margins of a basin has only a fortuitous relationship to that of the margins of the ancestral basin in which deposition took place. In the case of the smaller basins which, like the Big Horn basin, are surrounded by greatly elevated mountain masses, this is of service to the geologists. Data from careful stratigraphic studies of outcrops on the adjacent mountain slopes around such basins may provide a reasonably satisfactory basis for predicting the occurrence of potential reservoirs at depth in the basin.

In the case of the larger basins, such as the Powder River basin, No. 9, or the Anadarko basin, No. 21, strata of potential importance in the accumulation of oil and gas are either not seen in outcrop at all or only at such distances that projection of shore line trends into areas of exploration have no valid foundation. Complete utilization of the geologist's skills is necessary to minimize unsuccessful drilling prior to discovery in areas of this type. Recognition of stratigraphic horizons by use of micropaleontology and of association of rarer minerals has become a normal function of the petroleum geologists. Compilation of stratigraphic data from wells in the form of maps showing the areal geology below a major unconformity is a valuable practice employed in the Midland basin and other areas. In the past, these geologic tools have been employed more largely for the interpretation of structural conditions than in reconstruction of the complete geologic history of the potential reservoirs and associated strata. It is obvious that the latter type of geologic interpretation usually requires much more data than the former. Nevertheless, every effort must be made to develop and use new criteria leading to the earliest possible recognition of all physical elements prevailing at the time of deposition, for only in that way can the geologist make his full contribution to the continuing discovery of oil and gas on a reasonable cost basis.

FUTURE OF EXPLORATION

The bearing of economic considerations on the choice of territory for exploratory activity is too often overlooked. In times of depression in the past the value of crude oil produced in the United States has tended to follow the trend of national income to a marked degree. During such times, there is no economic incentive for exploitation of less desirable oils nor for the exploration of prospective oil areas far from adequate markets. These relationships adequately explain the lack of interest in further exploration of the Rocky Mountain and Permian basin areas observed 10–12 years ago. They are important in considering the future,

for the high level of national income necessary for the continuation of the present economic situation would assure a high dollar value for crude-oil production in the United States for several years, thus largely removing geographic barriers to the exploration of even the more remote prospective areas. For that reason, consideration of all the prospective areas, regardless of their location, is now justified.

In the future, the important additions to the oil and gas reserves of the United States will be discovered in the deeper parts of the sedimentary basins. This conclusion is based on the status of exploration of the sedimentary areas, the volume of untested strata, and the geology of these areas as presently known. The discovery prospects for some basins appear to be much better than for others. Some have been explored to a large extent and their important contributions to the oil and gas supply are already known, others have been partly explored and data are available for their general evaluation as sites of future discovery, while others are so little tested that their potentialities are entirely a matter of speculation to be evaluated by considerable exploratory effort.

It is evident that the demand for oil production will provide the economic stimulus required for this exploration, much of which will have results more important for the additions to be made to the reserves of natural gas than for oil. Consequently, in looking for gas for the future we may be concerned mainly with the question of which of the basin areas appear to have the best prospects of containing the reserves which will be needed. The following portion of this paper is concerned, therefore, with a general discussion of the known basin areas of the United States. The data considered have been obtained almost entirely from published sources. The conclusions reached are neither based on complete knowledge of current exploratory efforts nor prejudiced by personal interest in the outcome of exploration of any particular area. It is hoped that one of these factors may serve to compensate the other to a considerable extent with the result that the conclusions presented are reasonably valid.

OIL AND GAS PROSPECTS OF BASIN AREAS

Most of the more important sedimentary basin areas of the United States are shown in Figure 2. The map is not intended to show the precise location or area of each basin, but is a general reference guide for purposes of identification.

The classification of the discovery prospects of the basin areas is largely dependent on an interpretation of geologic conditions. Geophysical surveys may provide data on the folding of buried strata, but in the central portions of the larger basins exploration by drilling is necessary to determine the location of satisfactory reservoir rocks. Consequently, it must be recognized that in addition to the known geological conditions, the status of exploratory drilling must be considered in each case.

Table II lists each of the areas numbered on the map, gives some of the published data as to the area and volume of each basin, and classifies each in accord-

ance with the writer's opinion about discovery prospects. The scheme of classification used is designed to indicate the status of exploration as well as the predicted future of exploration results. The key to the classification is as follows.

PROSPECT CLASSIFICATION

A. Considerable exploration, good gas reserves
   1. Both additional areas and greater depths to be tested; probable discoveries very important
   2. Main prospects in structures obscured by shallow formations; good discoveries probable
   3. Remaining undiscovered reserves probably of moderate size
B. Some exploration, some good fields
   1. Excellent prospects for additional reserves
   2. Fair prospects for additional reserves
   3. Future discoveries of importance doubtful
C. Some exploration, results inconclusive
   1. Prospects of discoveries appear good
   2. Prospects of discoveries appear fair
   3. Prospects of discoveries appear poor

A considerable part of the basic information for the map (Fig. 2), and for Table II, was obtained from "Possible Future Oil Provinces of the United States and Canada," a symposium of the A.A.P.G. published as the May, 1941, number of the *Bulletin*, the "Tectonic Map of the United States," published by the A.A.P.G. in 1944, and the United States Geological Survey's "Geologic Map of North America." Modification and expansion of these data will be recognized. Exploratory drilling since the date of these publications has provided further information as to the oil and gas prospects of some of the basin areas and has been considered in the preparation of this paper.

Of the Pacific coastal areas, only No. 3 has been explored extensively. Additional gas discoveries of moderate size appear probable for this area. Marine sediments of considerable thickness are known in the other coastal basins, but exploration to date is inconclusive. It is possible that volcanic activity subsequent to the deposition of the potential oil- and gas-bearing sediments in the northwest has adversely affected these areas.

The basins in the Rocky Mountain states are believed to have generally good discovery prospects. Area No. 6 in northern Montana is given a low rating because of the extreme difficulty of solution of exploration problems arising from the very complicated structure of the mountain-front area. It must be recognized, however, that one or more fields of the Turner Valley type might be found even though there is little encouragement in drilling results thus far. The South-Central Montana basin, No. 7, contains many well defined anticlinal structures which have been tested through the Cretaceous formations with unfavorable results. Older formations, which are not well known, remain to be tested in the area and have recently been proved to have some prospect of production. Area No. 9 has exploration problems yet to be solved, but older fields in the southern part of the Powder River basin and recent developments to the northeast permit an optimistic view of the future of the area. The remaining basins in Wyoming are rated highly because of excellent results being obtained in exploration and the large areas of thick sediments yet to be explored. The basins to the south along

TABLE II

DATA ON OIL AND GAS DISCOVERY PROSPECTS OF SEDIMENTARY BASINS IN UNITED STATES

Map No. (Fig. 2)	*Basin Name*	*Area (Square Miles)*	*Total Sediments (Cubic Miles)*	*Prospect Classification*
1	Puget Sound	21,000	35,000	C-2
2	West Oregon	22,000	35,000	C-3
3	Sacramento	22,000	50,000	A-3
4	Salinas	3,000	4,000	C-3
5	Imperial Valley	5,000	6,000	C-3
6	North Montana-Mountain Front	1,900	3,800	C-2
7	South-Central Montana	2,000	4,000	C-2
8	Big Horn	3,000	9,600	A-2
9	Powder River	32,000	96,000	B-2
10	Williston	34,000	42,000	C-3
11	Wind River	2,500	6,000	B-1
12	Bridger	10,000	20,000	B-1
13	Washakie	7,000	14,000	B-1
14	Uinta	13,000	18,000	B-1
15	Colorado River	19,000	25,000	C-1
16	Black Mesa	12,000	18,000	C-1
17	San Juan	12,000	16,000	B-1
18	Denver	36,000	70,000	C-2
19	Delaware	8,000	15,000	C-2
20	Midland	43,000	75,000	A-1
21	Anadarko	45,000	90,000	A-1
22	Salina	60,000	36,000	C-3
23	Forest City			
24	McAlester	12,000	18,000	B-2
25	East Texas	14,000	21,000	B-1
26	Gulf Embayment	135,000	400,000	A-1
27	Mississippi Valley	33,000	30,000	C-3
28	Mississippi Salt Dome	21,000	42,000	B-1
29	Southwest Georgia	12,000	18,000	C-2
30	Florida	38,000	75,000	C-2
31	Illinois	37,000	25,000	B-3
32	Michigan	28,000	25,000	B-3
33	Appalachian	94,000	210,000	B-2
34	Hatteras	9,000	18,000	C-2

the Colorado-Utah boundary appear likely to contain important oil and gas reserves. A major oil field has already been discovered in No. 14 at Rangely and a major gas field in No. 17 at Barker Creek dome. Further, it seems probable that the Church Buttes field in No. 12 is very important. Comparable geological conditions in other parts of these basins will probably be found and should lead to the discovery of similar fields. Exploration of these deeper basin areas will be hampered by the thick cover of undisturbed strata and by difficulty of access to the areas, but the prospects of ultimate discovery appear good.

In the western plains area, the Williston basin, No. 10, does not seem particularly promising. Area No. 18 thus far is productive only along its western margin; elsewhere it is largely unexplored and is believed to have fair prospects of oil and gas discovery in the large volume of sediments remaining to be explored. The relatively small Delaware basin of West Texas and southeast New Mexico has similar prospects. The large Midland basin is already known to contain large

reserves of oil and gas, and in recent years has been the scene of some of the best discoveries in the United States. Recent additions to geologic data indicate further important volumes of sediments meriting exploration with every expectation of similarly satisfactory results.

The northernmost basins of the Mid-Continent area have been explored to a considerable extent, and on the basis of the poor results to date and the relatively small volume of sediments to be tested, are not considered to have important prospects. Although only a small part of the Anadarko basin, area No. 21, has been explored, the substantial discoveries made in the southern part of the basin combined with the expectation of favorable geological conditions over much of its large area and the large volume of sediments to be tested lead to the conclusion that discovery prospects are good. Recent developments substantiate the favorable rating given this area, and are considered indicative of the type of successful exploration which will be carried on for a long time to come. The McAlester basin, No. 24, has fairly good discovery prospects although the generally poor quality of the reservoir beds indicates that only modest reserves are likely to be found.

Exploration of the Illinois and Michigan basins, Nos. 31 and 32, is not complete but is sufficient to indicate that only unimportant gas reserves are likely. Much larger volumes of sediments remain to be explored in the Appalachian basin, No. 33, but widely distributed wells have penetrated the entire thickness of prospective producing formations and provide evidence that the old sediments remaining to be tested in this area include only a small part of potential reservoir beds, and that these generally are of poor quality. Discovery of additional reserves of local importance is anticipated, but the prospects of making substantial contributions to the Nation's supply of gas do not appear very good.

Potentially productive formations have been deposited along the Atlantic coast from the vicinity of New York southward, across Florida and along the Gulf coast. These formations extended inland for considerable and varying distances and were also deposited out to the submerged borders of the continent. Only the areas of general depression in this area are indicated on the map, for elsewhere the marine sediments are comparatively thin and apparently lacking in potential source materials. Area No. 34 is little explored, but does not appear to have much promise. Areas 29 and 30 are likely to be satisfactorily productive, but further data on the variation in character of buried sediments are required before conclusive exploration results can be obtained.

The middle and lower Mississippi Valley area, No. 27, had been explored in part without encouraging results. The Mississippi salt-dome basin, No. 28, is known to contain important fields and has excellent prospects for additional discoveries, particularly in formations at considerable depth. Only recently deeper drilling has indicated the possibility that favorable reservoir conditions will be found in these strata and that they will produce important amounts of oil and gas.

The East Texas salt-dome basin, No. 25, is of modest volume but appears likely to contain important additional reserves to be discovered after additional

well data permitting the solution of geologic problems have been obtained.

The Gulf embayment area of the Rio Grande valley, which extends for a considerable distance back from the present Gulf and along it to the Mississippi, comprises the largest volume of favorable sediments of any basin in the United States. Exploration has been extensive and in recent years drilling depths exceeding two miles have become rather common. During the exploration of the past 30 years important reserves have been discovered in various buried shoreline trends which generally parallel the present coast. In most parts of the area, exploration to depths of one mile has been sufficient to have discovered most of the important oil and gas fields down to that depth. Exploration in parts of the area, notably in the Agua Dulce-Stratton-Seeligson sector, is even now proving the existence of substantial additional reserves at modest depths, and will probably continue to do so for a few years to come.

For the future, exploration of the Gulf embayment may be expected to yield important discoveries in at least three different classes: (1) deeper zones present below known structures now productive, (2) deep zones on geologic structures without expression in strata now tested, and (3) new structures on the submerged parts of the continent. Although many of the more important structures have been tested to important depths below the present producing zones, the continuing success of deep drilling in some fields, and particularly around the flanks of the salt-dome structures provides a basis for confidence that such discoveries will be important. In regard to the second and third classes, it may be pointed out that the volume of untested sediments below depths of $1\frac{1}{2}$ or 2 miles is very large in this area, and undoubtedly contains good reservoirs now unexplored. The offshore and submerged areas are clearly in a very preliminary stage of exploration by drilling, although extensive geophysical surveys have been completed and are being continued. The solution of geological and geophysical problems necessary to discoveries in this area is confidently expected and will be accelerated by final determination of the ownership of mineral rights in those portions of these areas now in dispute. It is believed that the average thickness of the unexplored sediments in the Gulf embayment approximates $1\frac{1}{2}$ miles. Therefore, the volume of these unexplored sediments exceeds the total estimated volume of sediments in any of the other basins in the United States. Since it is believed that their average quality as source and reservoir beds at least equals that of most other basins, it is concluded that the most important undiscovered oil and gas reserves of the United States are located in this area.

ECONOMIC CONSIDERATIONS

The foregoing discussion has been based primarily on a consideration of geologic conditions and disregards the factors of availability of supply to markets, of delivery capacity to be expected for various types of fields, and of anticipated producing conditions. Recent meetings of natural gas associations have been devoted to discussion of long-range natural-gas transportation projects. This interest, being rapidly transformed into the factual planning stage, demonstrates

that if there is an important areal concentration of markets for large supplies of gas, market outlets for important gas-producing areas will be available. Nevertheless, consideration of the map will show that some areas possess important geographic advantage over others. The use of gas to be produced from the basins at great distances from markets will be determined in a large measure by the reserves and availability of gas in such basins.

Of the important prospective basin areas, those near the Rocky Mountains, Nos. 8–18, are without present or announced market outlets commensurate with their indicated gas resources. The ultimate utilization of these resources apparently will be determined in large part by the rapidity of their actual discovery. If discovery of fields having total reserves measured in trillions of cubic feet is made in a few years within a reasonable area, there would be a basis for important long pipe-line outlets. Realization of these resources over a longer period is more likely to result in their utilization as a raw material and energy source for a substantial chemical industry. To a less degree, the undiscovered gas reserves of the basins presently having important pipe-line outlets will find utilization according to the same economic principles.

Emphasis has been given the greater depths from which the undiscovered gas reserves will be produced. These reservoirs, on the average, are under higher pressure than the presently proved reserves. As a result, larger parts of these reserves will be produced from fewer wells at satisfactory delivery rates without compression in the field. It is also expected that larger portions of the gas reserves in these deeper fields of the future will be found associated with oil and will be produced incidental to the production of oil. Accordingly, their availability will be best adapted to uses having a comparatively uniform demand rate. Both long transmission lines and chemical-plant uses have this characteristic.

SUMMARY AND CONCLUSIONS

Geological considerations indicate that the additional reserves of gas needed for the markets of to-morrow will come from the deeper parts of the important sedimentary basins in fields which will be discovered by exploration for oil. The average depth and pressure of these reservoirs will be greater than that of the present proved reserves. As a result, the reserves will be large compared with the reservoir volumes and larger parts of these new reserves will be producible for pipe-line use without field compression. Larger parts of these reserves also will be associated with oil and produced at relatively uniform rates over a considerable number of years. The important future discoveries which are confidently expected in the basin areas, when added to the proved reserves of to-day, should provide adequate gas for to-morrow. The additional gas required for the future will be available in a number of important sedimentary basins. The group of Rocky Mountain basins, the Midland basin, the Anadarko basin, and the Gulf Coastal basin appear to be the best prospective areas. In spite of the considerable past exploration there, future prospects in the Gulf coastal area are believed to be much greater than in any of the others.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1821-1822

GEOLOGICAL NOTES

NEW APPROACH IN STUDY OF ORIGIN OF OIL[1]

RAY P. WALTERS[2]
Cairo, Egypt

Most geologists agree that little progress has been made in the study of the origin of oil. Much thought has been given to the problem and many ideas have been presented, but it is hardly an understatement to say that general agreement has been reached only on its being organic in origin. No one has been able to present any real convincing explanation of just how the original organic material, whether it was animal, vegetable, or a combination of the two, was transformed into crude oil. By the nature of its occurrence, however, we are in a position to state with reasonable certainty that the oil was formed in certain series; we believe we know the source beds. But the deductions are based on the nature of the oil occurrence itself rather than on the characteristics of the source bed. We are not able to differentiate beds in which oil has and has not been formed.

A major reason for the difficulty of determining the origin of oil is the lack of a record of such origin either in the source bed or in the beds through which it apparently migrated. Working backward from an oil deposit we find that only a short distance from the original limits of concentration traces of oil in the producing sand are lacking. Also in most places where we feel reasonably certain that the oil originated in a shale above or below the sand in which it is found, we fail to find traces of oil in such shale.

The writer believes that if the oil formed as oil within the source bed and migrated as oil through porous beds, traces of such origin and movement would have been left. The only exception might be in the case of very light oils, but even in this case the chances would seem to favor the leaving of a record.

Supporting arguments for this statement can be had from studies made by petroleum engineers on the recovery of oil from sands and from the abundance of such traces in the case of fossil oil fields.

Petroleum engineers have found that after a certain maximum percentage of the original oil is recovered from a sand, the amount depending on such characteristics as viscosity of the oil and permeability of the sand, no more oil can be recovered. Water will pass through the sand but will fail to remove any of the residual oil. It can be argued, however, that the observations have been made over relatively short periods and the conclusions reached therefore need not apply in the case of geologic time. But fossil oil fields confirm the findings of the petroleum engineers. A very good example, unfortunately one with which not

[1] Manuscript received, July 26, 1948.

[2] Standard Oil Company of Egypt, S. A.

many members of the Association are familiar, is the Surani anticline in Rumania. Surface occurrences and information from wells strongly suggest that the Oligocene sands, which were at one time richly impregnated with oil, lost most of their oil during post-Miocene erosion. But, in spite of exhaustion at such an early time, the sands still contain strong traces of oil, both at the surface and down to depths of 1,500–2,000 feet (probably the original oil-water contact). In this case the oil, as shown by the remnants of the original deposit, was light, the sand was both highly permeable and porous, and there has been ample time for the movement of water to cleanse the sands thoroughly, if such cleansing were possible. This is in the area of the rich Rumanian Pliocene fields, and where, therefore, oil formed and migrated in large quantities subsequent to the exhaustion of the Oligocene sands mentioned. In fact, this happened on the Surani anticline itself; the basal Pliocene sand contains oil, different in character and distribution from that in the Oligocene.

(It is not thought that a detailed description of the complicated Surani anticline and the oil occurrences on it would serve a useful purpose here. It happens to be a good case with which the writer is familiar in favor of the point being made, but many readers will be able to furnish similar and better known examples.)

The lack of record of oil within source beds and within beds in which migration took place therefore needs to be explained. One possible explanation, and this is the point of this note, would be that during expulsion from the source bed and during migration the "oil" existed not as oil but in some state intermediate between the original organic material and the final product. It is suggested that some thought be given to this possibility, especially by chemists. That such an intermediate stage could have existed is suggested by studies which have been made of oil shale. These shales are reported to contain a substance called kerogen which appears to be just such a material. It gives up no oil to ordinary solvents but on heating is transformed into a substance strongly resembling crude oil.

Prior to the formation of oil could a liquid or gaseous "kerogen" have existed? If this can be answered in the positive and if the nature of such material can be determined, an important step will have been made in the problem of the origin of oil.

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DISCUSSION

CORRELATION OF SENTINEL BUTTE SHALE IN WESTERN NORTH DAKOTA

RAY V. HENNEN[1]
Midland, Texas

In 1943, the writer summarized the results of three seasons of field work devoted primarily to detailed correlation of lignite and other beds and to reconnaissance mapping in western North Dakota.[2] Roland W. Brown of the United States Geological Survey in a recent paper[3] has taken issue with certain of these correlations and has labelled others as "pretty well compounded with guess work."

When the writer began work in North Dakota in 1940, he had the benefit of 40 years of experience in mapping surface geology, 16 years of which were spent in successfully tracing and correlating coal beds and associated strata in West Virginia, much of the southern part of which was in a heavily forested area much more difficult to work than the open plains of North Dakota. Therefore, he could hardly be considered as a novice in this type of work. Many geologists working in the North Dakota had expressed the opinion voiced by Dr. Brown that the lignite and associated beds could not be successfully used for structural contour mapping. The writer believed otherwise and the results of his 3 years of work in the area confirmed his beliefs to his own complete satisfaction. The correlations were not guess work but were based on numerous detailed hand-level sections and the surface tracing of groups of beds from one locality to another. The actual mapping was not done in detail by plane-table surveys, but was largely reconnaissance in character, by the use of an aneroid for elevations, which were closely checked on known spirit-level determinations.

The purpose of the work was to obtain not only a regional structural picture as revealed by the surface strata but reliable correlations to map detailed structure of particular areas. The writer firmly believes that the results as shown on the map and cross section accompanying his paper and as explained in the text are fairly representative of the structural attitude and correlation of the surface Tertiary beds of the part of the Dakota Basin south and west of the Missouri River and that any errors are probably less than one contour interval (100 feet).

Structural data for beds south and west of Missouri River were reduced to an horizon at the top of a prominent "Marker bed" labelled "SS21" which is a distinctive silicified tree-bearing zone. Dr. Brown takes particular issue with the writer's correlation of this bed from Sentinel Butte (Point 1 on Profile, Fig. 1) to Sully Springs Railroad station (Point 3).

The writer's active work in the field began near Point 11 of Profile as shown on page 1572 southwestward and westward from Almont in Morton County. There he found that "SS21" was an excellent marker-bed which, taken in conjunction with the sequence of strata closely associated with it, or from Lignite 19 up to and including Lignite 24, could be traced over wide areas in Morton County and northward to the Missouri River and,

[1] Chief geologist, Hiawatha Oil and Gas Company. Discussion received, July 29, 1948.

[2] "Tertiary Geology and Oil and Gas Prospects in Dakota Basin of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 12 (December, 1943), pp. 1567–94.

[3] "Correlation of Sentinel Butte Shale in Western North Dakota," *ibid.*, Vol. 32, No. 7 (July, 1948), pp. 1265–74.

largely along the north valley wall of the Missouri, northwestward to the Nesson anticlinal dome in southern Williams and northern McKenzie counties.

It is the writer's belief and judgment that "SS21" of the Almont region at Point 11 of Profile (Fig. 1) is one and the same bed as that which emerges above Andrews Creek near Sully Springs Railroad station at Point 3 of Profile. There he carefully measured a detailed hand-level section up the steep north hillside of Andrews Creek and tied into the section both Lignite 21 and "SS21." The former makes a distinct band of "scoria" westward along both hillsides of Andrews Creek, thus making it easy to trace. Then, farther west down Andrews Creek, another section was measured with hand-level from the bed of the creek and base of the lower Medora Coal (Lignite 15) near center of south line of Sec. 1, T. 130 N., R. 102 W., northward up the steep hillside of Andrews Creek to the base of Lignite 21. The strata in these two combined hand-level sections were carefully traced westward and northwestward and tied into or superimposed on top of the diamond-drill boring at Medora, the detailed log of which is incorporated in the section given at Point 2 of Profile, Fig. 1.

At the east edge of Medora at an elevation of 2,310 feet, Lignite 16 is mined. Here it belongs 300 feet below the top of "SS21" and 375 feet below Lignite 22 as classified at Point 2. The outcrop of Lignite 16 may be readily traced westward along U. S. Highway 10 to the Billings-Golden Valley county line, where it lies 375 feet (aneroid measurement) below the "scoria" of Lignite 22 of Point 1 of Profile (Fig. 1). The latter may be readily traced eastward from Sentinel Butte along the north side of U. S. Highway 10 by its thick band of "scoria" to the same point on the Golden Valley-Billings county line, heretofore cited. This corroborates the correlations of both Lignite 22 and "SS21" at Points 1, 2, and 3 of Profile (Fig. 1) as explained in detail in the first two paragraphs on page 1576 of the writer's paper.

These details refute the assertion by Dr. Brown that between Sentinel Butte and Sully Springs Station the writer confused two silicified zones. It is believed that if Dr. Brown had studied the sections in more detail he would have found the correlations correct.

Determination of the age of the Sentinel Butte beds, whether Paleocene or Eocene, was not a part of the writer's problem and he accepted the current opinion that these beds were basal member of the Wasatch (Eocene) formation. He is quite willing to accept Dr. Brown's opinion that they are Paleocene in age.

NEWS OF THE PROFESSION

GEORGE Y. MCCOY has resigned as valuation engineer for the Republic National Bank of Dallas in order to engage in consulting petroleum engineering and geology. His office is at 3208-B McKinney Avenue, Dallas, Texas, until October 1, 1948, when he will be at the Empire Bank Building, Dallas, Texas.

WINTHROP P. HAYNES, of the Standard Oil Company (New Jersey), New York, has been reappointed visiting lecturer in petroleum geology at Harvard University for 1948–49.

GEORGE MURRAY GILTINAN, of the Seismograph Service Corporation, Tulsa, Oklahoma, died at the age of 61 years, while on vacation at Victoria Harbor, Ontario, Canada, August 3.

GLEN H. BOWES is newly appointed manager of explorations for the Hudson's Bay Oil and Gas Company, Ltd. He has been with the Continental Oil Company 25 years at Los Angeles.

The executive committee of the Association met at Lander, Wyoming, August 11, previous to the field conference of the Wyoming Geological Association in the Wind River basin.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

PHOTOGRAMMETRY IN GEOLOGY—A SYMPOSIUM

REVIEW BY FRANK A. MELTON[1]
Norman, Oklahoma

"Photogrammetry in Geology—A Symposium," compiled by H. T. U. Smith, with papers by many authors. *Photogrammetric Engineering*, Vol. 13, No. 4 (December, 1947), pp. 531–628, illus. Published by the American Society of Photogrammetry, Box 18, Benjamin Franklin Station, Washington, D. C. Price, per copy, $1.50.

This symposium is a commendable attempt to enlighten aerial photographers and cartographic engineers about the use of aerial photographs by geologists. It will also enlighten the geologists, who are urged to read these papers if they can be secured. The contributions are short and concisely written; some are well illustrated with 120-line halftones. Such a screen is not so good as a finer one, and in fact is just barely adequate for aerial photographs; but the illustrations are still interesting. Some of the stereo-pairs are too dark, as is commonly the case with half-tones.

Several of the papers present fairly complete bibliographic lists dealing mainly with the geologic interpretation of aerial photographs. By checking one against another, the reader will be able to assemble a good bibliography. One paper (Rooney and Levings) presents a list of geological photographs that may be purchased from the Department of Mines and Resources, Ottawa, Canada.

Some of the contributors feel that aerial photographs open new fields of observation and of thought; others (Putnam especially) feel that the photographs are merely a new and very useful tool in the hands of the field geologist. The reviewer is aligned with the first group. He feels that aerial photography is not an end in itself, any more than is field work; both are indispensable to the correct three-dimensional modeling of geological districts.

This symposium does not have any papers dealing with the most advanced phases of aerial photo-interpretation as applied to oil exploration. The economic possibilities of such interpretation are still being studied.

Some of the contributors mention the desirability of having good, clear, large-scale photographs for geological study. This coincides with the reviewer's own experience. The best geological interpretation will be done when photographs are made to geological specifications and not necessarily to those of the cartographic engineers, who, after all, have a different problem to solve from that of the geologists. In the plains country of the central United States, and also in the coastal plains, it is evident to experienced photogeologists that at least half of the 1/20,000 photographs thus far made by the Department of Agriculture (the most prolific domestic source of aerial photography) will not show bedding in the bedrock exposures. The percentage of photographs in which bedding is not visible may be much greater than one-half. Moreover, there are large areas of outcropping bedrock in which photographs at this scale reveal no bedding at all. In many cases it is possible to interpret the strike and dip of bedding from its topographic effects; but this is hazardous where the dip is less than one degree, since, here the topographic effects commonly are obscure. Commercial photographs made at scales less than 1/20,000

[1] University of Oklahoma. Review received, June 25, 1948.

are even more difficult to use for geological interpretation. In mountainous country scales as small as 1/40,000 or even less may be used for extension of control and for mapping prominent geological features. For the smaller geologic anomalies, however, the pictures must be made to larger scales.

Original geologic observations are made by Rooney and Levings, Wengerd, Fortier, and Thwaites. The balance of the papers are concerned mainly with methods of planimetric map compilation or map construction.

The fifteenth, and last, contribution of the symposium is a general discussion of the geologic use of aerial photographs in college and university courses. The reviewer judges that this part is not complete.

PAPERS IN SYMPOSIUM WITH BRIEF COMMENTS BY REVIEWER

Mark Baldwin, Howard M. Smith and Howard W. Whitlock. "The Use of Aerial Photographs in Soil Mapping." 5 pp.

The authors give some of the early history of soil mapping with aerial photographs. But the principal contribution is an explanation of procedure in the use of aerial photographs for soil surveys. They point out especially that one is freed from the tyranny of the "long traverse"; that one can leave considerable detailed tracing and inking to cartographers—thus freeing the soil scientist for his own type of work. *A similar procedure would no doubt also yield big returns in geological work.*

They warn against the assumption that all parts of a photograph have the same scale; and, if only one set of contact prints is available, they strongly recommend that compilation of the base map be done before the field mapping. Soil mapping with aerial photographs takes more time than older methods which do not require the photos. The main advantage lies in the greater detail and the greater accuracy that can be secured with photographs.

Robert S. Dietz, "Aerial Photographs in the Geological Study of Shore Features and Processes." 8 pp., illus.

This paper is of interest to geologists. It contains information about the use of aerial photographs in: (1) determining the depth of sea water near shores; (2) the detection of submerged topographic features; (3) the recognition of modern and ancient, shore features; (4) recognizing sediment in process of transportation through turbid ocean water; and (5) recognizing cyclic shore changes, both seasonal and annual, as well as shore changes artificially induced. The photographs are among the best in the symposium.

Y. O. Fortier, "Geological Mapping of the Ross Lake Area, Using Air Photographs." 3 pp.

This is one of the more detailed papers. It presents the criteria and describes the results obtained by geological use of aerial photographs in the Ross Lake area, N.W.T., Canada —an area for which no base map was available. The district used for the example is one of crystalline rocks; hence the results will not have direct bearing upon aerial-photo use for oil and gas exploration. But the criteria for geological interpretation, and the formulation of hypotheses (on p. 546) will be useful to any geologist.

A. H. Lang, "Air Photographs in Geological Mapping of Cordilleran Region, Western Canada." 2 pp.

Lang describes the usual procedure for field use of aerial photographs in British Columbia and in the foothills of Alberta. He points out the advantage of being able to plan the traverse so as to have more contact with important outcrops and thus to save time.

R. C. Moore, "Aerial Photographs as Aids in Stratigraphic Studies." 7 pp.

Especially important is the method described here for measuring stratigraphic sections with the use of aerial photographs. Moore describes a method for making vertical angle measurements to points visible and identifiable both in the field and on the photographs. The pictures, presumably enlarged, are used as base maps, the scale having been previously checked. Using successive photographs on a plane-table board, and using distances determined by scaling the photographs, it was possible for him to make a 60-mile traverse in less than one day, checking in on a bench-mark at the end of the run with an error of only 4 feet in elevation. This method, moreover, can be applied by one man working without assistance. Knowing what we do about the inequalities of horizontal scale in aerial photographs, it seems that one using this method should be especially on guard against compensating errors.

The remainder of the paper is concerned with (1) a method of indexing vertical photographs for ready use, and (2) a simple statement of stratigraphic concepts for readers who are not at home in this field of geology.

Wm. C. Putnam, "Aerial Photographs in Geology." 8 pp. (chiefly illus.) and a bibliography of 16 references.

The author of this paper mentions various aspects of geology that may be usefully studied with the help of aerial photographs—such as sand dunes, levees, beach ridges, and also the more outstanding structures. He seems to feel that the study of aerial photographs should be undertaken merely as a basis for field study and field mapping. This is a statement with which the reviewer can not agree, since he feels that in each geological locality the aim is complete understanding rather than just that degree of comprehension which could be authenticated by field observation. But the study of photographs is not an end in itself; the reviewer knows of no one who takes this viewpoint. Aerial photo-interpretation is of considerable help in the discovery of structural anomalies; it could be much more helpful if properly used.

John L. Rich, "Geological Applications of Oblique Photography." 5½ pp.

The author outlines an approximate method of estimating dips, strikes, and the position of structure contours from oblique photographs. He describes a method of making an aerial traverse. A "flight curve" is constructed from a flight "time coordinate" and a "distance coordinate."

G. W. Rooney and W. S. Levings, "Advances in the Use of Air Survey by Mining Geologists." 13½ pp.

Part I.—The first part of the paper deals with the aerial photographs flown for geological research purposes in the Beatty-Munro area, District of Cochrane, northern Ontario, Canada. It is especially important in describing the photo-technique that gives the best geological results in ore mining. It is evident that the best technique in mining should be at least comparable with that of oil and gas exploration. For example, the authors give: (1) the best scales for reconnaissance, regional, and property maps; (2) suitable focal lengths for the camera lenses; (3) the best filter to accentuate color differences (red); and (4) the time of year for best rock visibility—spring in northern Ontario (no doubt winter time in more southerly latitudes). Some of their conclusions are quoted. P. 574, bottom.

(1) The red filter produced photographs with the best resolution of detail in the rock outcrops and it also produced the best contrast between the rock outcrops and the vegetation. The minus blue (yellow) filter produced almost as good results as the red, and the green filter produced poor contrasting results.

(2) None of the filters aided in detecting weathering colour not found by the other two filters.

P. 579, middle. Summarizing the interpretation and mapping value of the photographs in the Beatty-Munro area.

(1) All the rock outcrops could be seen and mapped from the photographs.
(2) Rock formations with yellow to white weathering colors (quartz porphyry, sericitized rhyolite, greywacke, serpentized peridotites) could be differentiated from the rocks weathering to pale rusty or darker colours and their contacts drawn.
(3) Most of the faults located on the ground could be located by their topographical expression on the photographs. Additional faults and extensions of known faults were indicated also.
(4) Small fracture patterns too numerous to map on the ground could be mapped quickly on the photographs.
(5) Much more geological detail was evident, of course, on the 400 feet = 1 inch photography than on the 1,000 feet = 1 inch photography.
(6) Practically none of the above geological detail interpreted from the photography made in spring before the hardwoods were in leaf was visible on the summer photography in the same area.

Pp. 579–80. Suggested scales from experience with air surveys for mining companies, in Canada, for various types of geological mapping programmes are:

(1) Reconnaissance Mapping:
Photography 2,000 feet = 1 inch.
With rough laydown mosaics at 1 mile = 1 inch.

(2) Regional Mapping:
Photography 1,000 feet = 1 inch.
Controlled mapping 1,000 feet = 1 inch.

(3) Mining Property Maps (size of area up to 5 square miles):
Photography 400 feet = 1 inch.
Controlled mapping 200 feet = 1 inch.
Controlled mosaicing 200 feet = 1 inch.
Enlargements to 100 feet = 1 inch for more detailed mapping of ore zones.

Part II.—(Rooney and Levings). This is a description of a 15-week course on the use and interpretation of air photographs, at Colorado School of Mines.

F. T. Thwaites, "Use of Aerial Photographs in Glacial Geology." 3 pp., illus.

He gives new information about glacial deposits left by continental ice sheets. He illustrates the aerial-photo recognition of these deposits—such as pitted outwash plains, moraines and eskers. More illustrations are needed for this paper.

Sherman A. Wengerd, "Geologic Interpretation of Trimetrogon Photographs—Northern Alaska." 13 pp., illus. Bibliography.

This is one of the more detailed geological articles in the symposium. It presents new information[2] about the geomorphic expression of strike and dip of sedimentary rocks. The facts about solifluction also are new, so far as the reviewer knows.

In addition to the geological study of photographs, their use for base maps is fully described, including information on the choice of scale, focal length of lens, construction of templets, *et cetera.*

John L. Rich, "Reconnaissance Mapping from Oblique Aerial Photographs without Ground Control." 9 pp.

Rich presents a method for making a reconnaissance map from oblique photographs, without ground control. The procedure does not require that the entire area be essentially flat, as does another previously described method. Geologists may find this useful for

[2] Also presented by Norman C. Smith and Sherman A. Wengerd, "Photogeology Aids Naval Petroleum Exploration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31 (1947), pp. 824–28.

approximate maps of small areas which can be covered by a few photographs; larger areas will of course require control.

John D. Strobell, Jr., "The Multiplex Compilation of Geologic Maps." 6 pp.

Geologists will find this article to be of considerable interest. It describes in detail the various steps necessary to publish a geologic map on a multiplex-compiled base map. In addition, some of the limitations of the Mahan and the K. E. K. plotters, as well as limitations of the Multiplex method are given.

One great advantage of the Multiplex is that several adjacent models in a flight strip may be set up together and adjusted as a group, which permits uncontrolled intervals to be spanned or "bridged" between established control points. The map accuracy requirements limit the length of the bridge. The intersection angle of the two rays that define a point in the model is such that vertical elevations are less definite than horizontal positions, so that "horizontal bridging" is more accurate over longer distances than "vertical bridging."

H. T. U. Smith, "Aerial Photos in Geologic Training." 4½ pp. Abridged from a paper published in the *Interim Proceedings* of the Geological Society of America for March, 1947.

Smith gives his views on the proper use of aerial photographs in university teaching. These views are beyond doubt good. He concludes, p. 619:

. . . aerial photographic methods are here to stay. Their use is now standard as a method of geologic investigation. Their advantages apply alike to theoretical geology and to applied geology. Their application already has given rise to appreciable advances in geologic knowledge, and now holds much promise for future progress. Their value merits a definite place in the training of the professional geologist. If the teaching of geology is to keep pace with the practice of geology, photo-interpretation and photo-mapping must be included in the curriculum.

The reviewer would not recommend that students be required to take courses in photo-mapping. The list of required accessory subjects, or tool subjects, is already large in the geologic curriculum. Further additions will hasten the day when genuine geologic field experience will receive very little of the undergraduate's time and interest. It will be sufficient if construction of base maps be left to photogrammetric engineers or at least to those geologists interested in this engineering subject.

THE GEOLOGY OF THE OIL REGIONS OF WARREN, VENANGO, CLARION, AND BUTLER COUNTIES, BY JOHN F. CARLL

SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA III, 1880

REVIEW BY J. V. HOWELL[1]
Tulsa, Oklahoma

It is now more than 68 years since this book was published, and the only excuse for this review is that so few geologists appear ever to have seen it, or know that it exists.

The first 17 chapters, embracing 164 pages, are devoted to discussion of stratigraphy, and lithology of the producing beds. Chapters 18–30 (pp. 164–329) constitute a textbook on petroleum engineering and drilling practice as it was known in the period of 1875–1880. It is this part of the book that is of interest to geologists.

Chapters 18–22 describe methods and difficulties of obtaining good well records, and discuss records of several wells in which records were kept by Carll's approved methods. Some of his suggestions follow.

[1] Consulting geologist.

1. Concerning geologists. "His vocation seems to be generally misunderstood by the well informed oil producer, as by the most illiterate rustic."

2. To remedy defects in the records " . . . it was found necessary to employ a special assistant for the purpose of securing a few accurately measured and detailed well sections in different localities." In other words a "well sitter."

3. Methods of measurement including "stringing in" and use of a wire line are discussed, and suggestion is made for use of "a wheel which could be held in the hands and pressed against the cable as it ascended, the revolutions of the wheel to be recorded by an index, on the same principle as the odometers used on the survey. The wheel was made and works nicely. . . . " Carll states that J. F. Ramsey, in the spring of 1877, used a similar device on a well near Beaver Falls. Later (p. 186) he states that such a wheel has been patented and is in use in the Bradford Field.

4. Drilling-time logs. Probably few present-day geologists have used drilling-time logs of wells drilled by cable tools. But Carll tried them and obtained good results, as shown by his Plate XVII.

5. Saving of samples. Carll recommends saving two samples from each run of the sand pump, one as collected, and the other thoroughly washed. Reasons for this are fully discussed.

6. A unique method of correlating bottled samples on the "specimen time rack" is described (p. 211).

Chapter 23 discusses the probable mode of origin and accumulation of the oil sands. He concludes that he still is in doubt regarding this, but recognizes the presence of bars or "drifts."

Chapter 24 discusses crevices, and concludes that they are not necessary to account for large wells. In this connection Carll describes an instrument called a "crevice searcher," which bears no slight resemblance to certain instruments now in common use. The instrument is described as follows.

The cylindrical body of the "searcher," which was about two feet long, nearly filled the borehole. In lowering it, whenever a crevice was reached a little finger about an inch long (which was kept pressed out against the wall of the well by a spring) snapped out into the opening and checked the downward movement. Then by raising the rods until the finger struck the top of the crevice, its exact measurement could be obtained. When this was done and the depth recorded, the finger was drawn back by a cord running up along the rods to the well mouth, thus unlocking the instrument from the crevice and allowing it to be lowered until another one was found.

This was an excellent device for measuring the depth of a well, for the rods were accurately marked in feet and inches, and there could be no streach or slack to mislead, as in the case of measurements made by rope or wire. For several years it must have been the source of considerable revenue to its owners, as it was largely employed at a charge of thirty dollars for an insertion, to ascertain the most favorable point at which to explode a torpedo, when the original driller's record had been lost or could not be relied upon. The operators of the machine became so proficient in its use that they claimed to be able to tell the difference between shale, slate, and sandstone, by the sound and jar communicated through the rods at the well mouth, as the finger scratched against the changing strata in descending.

Chapter 25 is entitled "How Water Invades the Sandrock to the Exclusion of Oil and Gas. A Review of Some of the Circumstances Attending Its Occurrence." The views expressed here are astonishingly modern and this chapter may well be read by everyone interested in reservoir studies. Some of Carll's conclusions may be mentioned.

1. Early wells in a pool are more likely to prove profitable than later ones. (pp. 257–8)

2. Coarse or porous sands may be surrounded by nearly impervious rock so that drainage of one porous patch does not affect others nearby.

3. Oil and gas in their normal conditions appear to lie in the sandrock not as distinct bodies, occupying separate portions of the rock, but as one substance, the gas being as thoroughly incorporated with the oil, as gas is with water in a bottle of soda water. (p. 262)

4. The flooding of an oil district is generally viewed as a great calamity, yet it may be questioned whether a larger amount of oil can not be drawn from the rocks in that way than by any other, for it is certain that all the oil cannot be drawn from the reservoir without the admission of something to take its place.

If one company owned all the wells drawing upon a pool, and had accurate records of the depths and characteristics of the oil producing stratum in each well, it is quite possible that some system might be devised by which water could be let down through certain shafts, and the oil forced towards certain other shafts where the pumps were kept in motion, and thus the rocks be completely voided

of oil and left full of water. As it is however, no systematized plan of action can be adopted. The careless handling of one well, by which water is let down to the oil rock, may spoil several others belonging to different parties. A clashing of interests at once arises and is likely to result in disaster to the whole district.

On page 265, paragraph 480, is the following outline of considerations necessary before judging desirability of flooding.

1. Time of flooding, whether early in development or after depletion.
2. Texture and homogeneity of the reservoir.
3. Shape of the area to be flooded.
4. Position of input well relative to producing wells.
5. Height of column of water in input well. (Pressures above hydrostatic were not considered and would have been impractical.)
6. Duration of the water supply.

Chapter 26 is entitled "Origin of Oil—A Chapter of Queries." The conclusion reached is that the question of origin is one which "may be discussed, but not satisfactorily answered." With this statement few of us will disagree.

One wholly false conclusion may be noted, this being that oil has not yet been (in 1880) and probably will not be, found below sea-level.

Chapters 27 to 29 are devoted to drilling tools and rigs, and to pumping methods. These pages should be of particular interest to anyone who may have to interpret logs of wells drilled between 1860 and 1880. The changes in technique evolved during those years are discussed on pages 315–21.

Carll recognizes clearly many of the questions that still trouble us, such as the variable character of the oil in different sands, the lack of uniformity in changes with depth, the possibility that oil may be formed by condensation of gas, or conversely that gas may be formed by distillation of the oil. He concludes "But there are so many unknown factors involved in a solution of these problems that we must be content to work slowly and—wait." After 68 years of work we still are—waiting.

RECENT PUBLICATIONS

ALGERIA

*"Le Djebel Nador," by Paul Deleau. *Bull. Geol. Survey Algeria,* 2d Ser., Stratigraphy and Regional Description, No. 17 (Alger, 1948). 126 pp., illus. The Djebel Nador are ridges of mountains of Secondary age, 40 kilometers southeast of Tiaret and 225 kilometers southwest of Alger. Stratigraphy and paleontology of Triassic to Miocene. Report includes note on geology of Chellala Mountains. French.

CZECHOSLOVAKIA

*"Tektonika Územia Medzi Stredným Tokom Váhu a Hornou Nitrou" (Tectonics of Territory between Middle Váh and Upper Nitra), by M. Mahel'. *Geol. Survey in Bratislava Sŏsit 18* (Bratislava, 1948). 79 pp. (51–79 in English), 3 folded pls. (geol. map and sections).

*"Geological Map of Czechoslovakia Sheet Rajec 4361 (4)," by D. Andrusov and M. Kuthan. *Geol. Survey in Bratislava.* Sheet in colors, 38×27 inches. Scale 1:25,000.

EAST INDIES

*"Mikropaläontologische Untersuchungen des Tertiärs von Gross Kei" (Micropaleontological Study of the Tertiary of Grand Cay, Molucca Islands), by Jac. George Bursch. Reprint (1947) from *Schweizerischen Palaeon. Abhandlungen,* Bd, 65, Komm. Schweizerischen Naturforschenden Gesellschaft, Basel. 69 pp., 5 pls. of fossils, 22 text figs. In German.

ENGLAND

*"The Zonal Value of Foraminifera in the Chalk of England," by E. Williams-Mitchell. *Proc. Geologists' Assoc.*, Vol. 59, Pt. 2 (June 28, 1948), pp. 91–112; 1 pl. Benham and Company Limited, High Street, Colchester, England. Price of June number, 5/-.

ETHIOPIA

*Sinclair Meets Transport Problems in Exploring Its Ethiopian Concession," by Hall Taylor. *Oil and Gas Jour.*, Vol. 47, No. 14 (Tulsa, August 5, 1948), pp. 43–45, illus.

GENERAL

*"Symposium on Problems of Mississippian Stratigraphy and Correlation," by many authors. Edited by J. Marvin Weller. 13 papers. *Jour. Geology*, Vol. 56, No. 4 (Chicago, July, 1948), pp. 253–402, illus.

*"The Geosynclinal Theory," by Adolph Knopf. *Bull. Geol. Soc. America*, Vol. 59, No. 7 (New York, July, 1948), pp. 649–70; 3 figs.

*"Annotated Bibliography of Marine Geophysical and Geological Surveys," by Richard A. Geyer. *Ibid.*, pp. 671–96.

*"Assemblage Log—an Aid to Management," by Karl A. Mygdal. *Petrol. Engineer*, Vol. 19, No. 8 (Dallas, Texas, May, 1948), pp. 242–47; 3 figs.

GREAT LAKES AREA

*"Crustal Movement in the Great Lakes Area," by Sherman Moore. *Bull. Geol. Soc. America*, Vol. 59, No. 7 (New York, July, 1948), pp. 697–710; 2 figs., 1 pl.

GULF COAST

*"Basic Geology of the Gulf Coastal Area," by J. Ben Carsey. *Oil*, Vol. 8, No. 5 (New Orleans, Louisiana, June-July, 1948), pp. 16–18; 2 figs.

IRAN

*"The Production of Oil from the Fields of Southwestern Iran," by H. S. Gibson. *Jour. Inst. Petroleum*, Vol. 34, No. 294 (London, June, 1948), pp. 374–402; 17 line cuts, 5 halftones.

KANSAS

*"Upper Cambrian and Lower Ordovician Rocks in Kansas," by Raymond P. Keroher and Jewell J. Kirby. *Kansas Geol. Survey Bull. 72* (Lawrence, June, 1948). 140 pp., 6 pls., 13 figs.

"Geologic Map Index of Kansas," compiled by Leona Boardman and Annabel Brown. *U. S. Geol. Survey* (July 7, 1948). Compiled on a large base map; scale, 1 inch equals 12 miles. May be purchased from Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.30.

MEXICO

*"Exploraciones geológicas en el centro de la region oriental del Estado de Coahuila y en las porciones limitrofes del de Nuevo León" (Geological Exploration in East-Central Coahuila and Part of Nuevo Leon), by Federico K. G. Mullerried. Separate from *Bol. Soc. Mexicana Geografia y Estadistica*, Tomo 65, Núm. 1 (1948). 39 figs. (photographs and line drawings). Artes Graficas de Estado, Juan E. Hernández y Dávalos, 185, Mexico, D. F. Spanish.

*"Oil Exploration in Mexico Being Speeded as Nation Seeks to Expand Production," by Ben F. Rummerfield. *Petroleo Interamericano*, Tomo 6, No. 8 (Tulsa, Oklahoma, August, 1948), pp. 34–41; 7 illus. Spanish and English.

MIDDLE EAST

*"Review of Middle East Oil." *Petroleum Times Export Number* (London, June, 1948). "A comprehensive illustrated review of all aspects of current developments based on a recent extended tour of C. T. Barber, joint editor of *Petroleum Times*, with special contributions from outstanding authorities." 115 pp. 9.5×12.875 inches. Petroleum Times, 545 Fifth Avenue, New York, N. Y. Price, 7s.6d. ($1.50).

PUERTO RICO

"Tertiary Geology of the Coastal Plains of Puerto Rico," by A. D. Zapp, H. R. Bergquist, and C. R. Thomas. *U. S. Geol. Survey Prelim. Map 85*, Oil and Gas Inves. Ser. (August, 1948). 2 sheets, each 44×64 inches. Scale, 1 inch equals 5,000 feet. Map may be purchased from Director, U. S. Geol. Survey, Washington 25, D. C. Price per set, $1.00.

ROCKY MOUNTAINS

*"Limnology and the Eocene Lakes of the Rocky Mountain Region," by W. H. Bradley. *Bull. Geol. Soc. America*, Vol. 59, No. 7 (New York, July, 1948), pp. 635–48; 6 figs., 2 pls.

SOUTH DAKOTA

"Geologic Map Index of South Dakota," by Leona Boardman and Annabel Brown. *U. S. Geol. Survey* (July, 1948). Compiled on a large base map; scale, 1 inch equals 12 miles. May be purchased from Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.30.

WASHINGTON

*"Prospecting for Oil and Gas in Washington," by Sheldon L. Glover. *California Oil World*, Vol. 41, No. 13, 1st issue (Los Angeles, July, 1948), pp. 3, 5, 9, 1 fig.

WEST VIRGINIA

*"New Gas Developments in Southern West Virginia," by E. H. Tollefson, W. H. Mayfield, and A. R. McCamey. *Oil and Gas Jour.*, Vol. 47, No. 14 (Tulsa, August 5, 1948), pp. 82–91; illus.

WYOMING

"Geology of Boysen Area, Central Wyoming," by H. A. Tourtalot and R. M. Thompson. *U. S. Geol. Survey Prelim. Map 91*, Oil and Gas Inves. Ser. (July, 1948). 2 sheets, each 40×54 inches: May be purchased from Director, U. S. Geol Survey, Washington. 25, D. C. Price, $1.00.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 22, No. 4 (July, 1948).

"Ostracoda from the Upper Cretaceous and Lower Eocene of Maryland, Delaware, and Virginia," by Ruth A. M. Schmidt.

"Cretaceous Asteroids from California," by J. Wyatt Durham and Wayne A. Roberts.

"Additional Conodonts from the Sweetland Creek Shale of Iowa," by Walter Youngquist and A. K. Miller.

"New Cambrian Trilobite Genera from Northwest Sonora, Mexico," by Christina Lochman.

"Two New Eurypterids from the Silurian of Indiana," by Erik N. Kjellesvig-Waering.

"Note on the Stratigraphic Distribution of *Lepidorbitoides*," by C. M. Bramine Caudri.

"Two New Marine Ostracodes from the Tertiary of Washington," by I. G. Sohn.

"*Cribroparella*, a New Genus of Foraminifera from the Upper Miocene of Algeria," by A. ten Dam.

"Two Undetermined New Zealand Tertiary Fossils," by J. A. Bartrum.

"Notes on *Phanocrinus* from the Fayetteville Formation of Northeastern Oklahoma," Harrell L. Strimple.

"New Tertiary Brachiopoda from Japan," by Kotora Hatai.

"The Foraminifer *Orbulina universa* d'Orbigny, a suggested Middle Tertiary Time Indicator," by L. W. LeRoy.

"On *Asterigerina gurichi* (Franke), and Remarks on Polymorphism and the Stratigraphic Use of Foraminifera," by J. Hofker.

"Dorothy K. Palmer, 1897–1947," by Katherine van Winkle Palmer.

"*Holynocrinus*, new Crinoid Genus from the Middle Devonian of Bohemia," by Josef Bouška.

NEWS OF THE PROFESSION

Speakers and leaders on the field trip of the Ardmore Geological Society in southern Oklahoma, June 18–19 (left to right): MONROE G. CHENEY, Anzac Oil Company, Coleman, Texas; C. W. TOMLINSON, consultant, Ardmore; JEROME WESTHEIMER, Simpson-Fell Oil Company, Ardmore; and WALTER NEUSTADT, JR., president, Ardmore Geological Society.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1835-1848

ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Robert Jess Beams, Oklahoma City, Okla.
Phil C. Montgomery, Frederick H. Kate, R. W. Edmund

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Jean Cuvillier, Paris, France
J. J. Galloway, A. J. Eardley, E. Jablonski

George A. Dunaway, Cushing, Okla.
George W. Artman, Charles Robert Hoyle, A. M. Meyer

John W. Eiserloh, Elizabeth City, N. C.
E. Willard Berry, Marcus A. Hanna, Roderick A. Stamey

Adolphe Glenmore Gueymard, Houston, Tex.
George L. Nye, Shapleigh G. Gray, William Clyde Ikins

Marshall A. Hayes, Jr., Lott, Tex.
Guy J. Scholl, Donald Kelly, Bruce Whitcomb

Arthur Louis Jenke, Abilene, Tex.
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Edward Leslie Knaack, Tyler, Tex.
Philip S. Schoeneck, R. A. Brant, Henry J. Morgan, Jr.

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H. M. Bayer, C. D. Cordry, M. E. Upson

Gordon Andrew Macdonald, Los Angeles, Calif.
Thomas Clements, Francis P. Shepard, K. O. Emery

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Harold E. Culver, R. L. Lupher, S. H. Cathcart

George Carroll Taylor, Jr., Washington, D. C
Nicholas A. Rose, V. T. Stringfield, A. N. Sayre

Harold Edgar Thomas, Salt Lake City, Utah
V. T. Stringfield, A. Nelson Sayre, W. H. Whittier

Eduard Truempy, London, England
B. F. Hake, Harry L. Baldwin, Ben H. Parker

Charles V. Walton, Jackson, Miss.
J. C. Johnston, Carl F. Grubb, Knight K. Spooner

John Herbert Wiese, Hermosa Beach, Calif.
W. C. Putnam, M. N. Bramlette, L. W. Storm

Frederick Erwin Wright, Houston, Tex.
J. Boyd Best, Walter J. Boyle, Shirley L. Mason

FOR ASSOCIATE MEMBERSHIP

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Robert Whittington Baker, Pasadena, Calif.
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Hershel Spurgeon Carver, Jr., Norman, Okla.
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Erle William Gilbert, Montclair, N. J.
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R. J. Adams, John T. Lonsdale, P. M. McNally
Milton Sisson Hathaway, Jackson, Miss.
B. M. Choate, K. K. Spooner, Charles W. Sternberg
Charles Anderson Hinton, Lockhart, Tex.
S. A. Lynch, Harold Vance, Frederick A. Burt
William B. Hogg, Dallas, Tex.
W. M. Plaster, H. C. Vanderpool, Claude N. Valerius
William Edward Hollingsworth, Beaumont, Tex.
John D. LaTouche, K. V. Schroeder, Herbert Parker
John W. Honea, Houston, Tex.
C. H. Sample, A. F. Childers, Jr., Hershal C. Ferguson
Charles Hornberger, San Antonio, Tex.
Charles H. Row, Emil Monsour, W. M. Chaddick, Jr.
John Spencer Hyndman, Corpus Christi, Tex.
W. A. Ver Wiebe, T. G. Wright, J. Robert Berg
Wylie Bruce Johnson, Dallas, Tex.
M. E. Upson, Ellis W. Shuler, Claude C. Albritton, Jr.

Edward George Lipp, South Bend, Ind.
K. K. Landes, A. J. Eardley, Lewis B. Kellum
William Gordon McCoy, College Station, Tex.
Frederick A. Burt, S. A. Lynch, William L. Russell
William John McPherson, Saskatoon, Sask., Canada
F. G. Tickell, A. I. Levorsen, S. W. Muller
Wilbur Ross Moore, Dallas, Tex.
Don L. Frizzell, Hal P. Bybee, H. Gordon Damon
Eldon Joseph Parizek, Iowa City, Iowa
A. C. Trowbridge, A. K. Miller, Allen C. Tester
Mia Suverkrop Ramsaur, Los Angeles, Calif.
Lew Suverkrop, Edward C. H. Lammers, W. P. Winham
Richard Raymond Scurlock, San Angelo, Tex.
Hal P. Bybee, Russell M. Jeffords, H. B. Stenzel
Robert Burns Shaller, Golden, Colo.
J. Harlan Johnson, F. M. Van Tuyl, W. S. Levings
William Lesley Sheafer, II, Maracaibo, Venezuela, S. A.
George L. Lockett, Hans Herman Renz, John G. Douglas
David S. Sheridan, Greeley, Colo.
Warren O. Thompson, John R. Hayes, W. Warren Longley
William Taylor Short, Midland, Tex.
Ernest L. Berg, Allen Ehlers, Louis H. Michaelson
Paul S. Tremel, Hatfield, Pa.
J. H. Deming, J. B. Klecker, G. C. Pfeffer
Beulah Munson Waggoner, McCall, Idaho
Herbert M. Bristol, Homer Luttrell, Lindsay G. Morgan
Billie Wilson Walden, Hugo, Okla.
V. E. Monnett, E. L. Lucas, Carl A. Moore
Arvie Earl Walker, Big Spring, Tex.
Leroy T. Patton, Raymond Sidwell, W. I. Robinson
James Ralph Wilson, Jr., Fort Worth, Tex.
M. E. Upson, W. C. Morse, Glen F. Brown
William Harwell Wise, Shreveport, La.
V. E. Monnett, Keith M. Hussey, Carl A. Moore

FOR TRANSFER TO ACTIVE MEMBERSHIP

Howard Theodore Anderson, Rosemead, Calif.
W. H. Holman, Herschel L. Driver, W. P. Winham
George Edward Gosnell, Jackson, Miss.
Carl F. Grubb, Knight K. Spooner, Clement A. Weintz
Walter Randall, Beatrice, Ala.
W. Dow Hamm, O. C. Clifford, Jr., K. K. Spooner

REPORT OF NOMINATING COMMITTEE

San Antonio, Texas,
August 7, 1948

To the Executive Committee
Paul Weaver, *chairman*

In accordance with Art. IV, Sec. 2, of the Constitution, your nominating committee presents the following candidates for officers of the Association for the year 1949. Each nominee has expressed his willingness to serve.

For President—RONALD K. DEFORD, University of Texas, Austin, Texas
W. C. SPOONER, consulting geologist, Shreveport, Louisiana
C. W. TOMLINSON, independent, Ardmore, Oklahoma
For Vice-President—THEODORE A. LINK, consulting geologist, Toronto, Ontario
For Secretary-Treasurer—FRED H. MOORE, Magnolia Petroleum Company, Roswell, New Mexico
E. E. REHN, Sohio Petroleum Company, Evansville, Indiana
HENRY N. TOLER, Southern Natural Gas Company, Jackson, Mississippi
For Editor—ALFRED H. BELL, State Geological Survey Division, Urbana, Illinois
KENNETH K. LANDES, University of Michigan, Ann Arbor, Michigan

Respectfully submitted,
ED. W. OWEN, *chairman*
JOHN L. FERGUSON
FRANK A. MORGAN
BEN H. PARKER
JOHN P. SMOOTS

Note.—Photographs and biographies of candidates will be published in the November *Bulletin* provided they are received at Association headquarters not later than October 1.

SUPPLEMENTARY MEMBERSHIP LIST, SEPTEMBER 1, 1948

Members	129
Associates	236
Total additions since publication of list in March *Bulletin*	365

Adams, Wallace Wayne, Creole Petr. Corp., Apt. 1329, Caracas, Venezuela, S. A.
Agatston, Robert Stephen, Atlantic Refg. Co., Box 520, Casper, Wyo.
Alexander, Theodor Walter, Texas Tech. College, Box 153, Tech. Sta., Lubbock, Tex.
Almarza, Ramon Jose, Mene Grande Oil Co., Apt. 709, Caracas, Venezuela, S. A.
Anderson, Alexander, 244 E. Whiting Ave., Fullerton, Calif.
Armstrong, John Moore, Box 110, Russell, Kan.
Ashmore, Herman T., Amerada Petr. Corp., Box 2026, Tyler, Tex.
Atchison, Carl Hayden, Honolulu Oil Corp., Midland, Tex.
Baade, John Herman, Gulf Oil Corp., Box 2038, Pittsburgh, Pa.
Baldo, Felipe Eduardo, Creole Petr. Corp., Caracas, Venezuela, S. A.
Barton, Al H., 627 Cleveland, Lake Charles, La.
Barton, Harold Edward Sharp, Brinkerhoff Drilling Co., Box 655, Lander, Wyo.
Bates, Warren Jackson, J. M. Huber Corp., Box 831, Borger, Tex.
Beckley, Philip Wesley, Gulf Oil Corp., 3327 Douglas, El Paso, Tex.
Belchic, George, Jr., Belgam Oil Co., Shreveport, La.
Bellows, Clarence Ernest Stanley, III, The Texas Co., Box 262, Mt. Pleasant, Mich.
Blackmon, Walter Douglas, Gulf Oil Corp., Box 1047, Kermit, Tex.
Blexrud, Owen Hefte, Magnolia Petr. Co., Box 607, Lindsay, Okla.
Bloodworth, Bill Lloyd, Geophoto Services, Inc., 305 E. & C. Building, Denver, Colo.
Boatner, Prentis L., Jr., Apt. A-1, 3144 Woodlawn, Shreveport, La.
Bonnard, E. G., Societe Nationale des Petroles d'Aquitaine, 15, Rue Laganne, Toulouse, France
Brantly, John Edward, Jr., Box 182, Abilene, Tex.
Bruner, Alfred M., Shell Oil Co., Inc., Box 549, Carlsbad, N. M.
Burma, Benjamin H., Univ. of Nebraska, Lincoln, Neb.
Burns, Robert Howard, Knowlton Engineering Co., 2507 First Natl. Bldg., Oklahoma City, Okla.
Byers, John Carter, Sun Oil Co., Silver, Tex.
Byrne, Frank Edward, U. S. Geol. Survey, Manhattan, Kan.
Carlson, Harry William, 1827 S. Carrollton Ave., New Orleans, La.
Charlton, George Douglas, Moranda Oil Corp., 2101 Transit Tower, San Antonio, Tex.
Chavez, Eugene Alfonso, Mene Grande Oil Co., Apt. 45, Barcelona, Venezuela, S. A.

Chelikowsky, Joseph R., Kansas State College, Manhattan, Kan.
Christmann, John Joseph, Jr., consulting, Rt. 5, Lubbock, Tex.
‖Clampitt, Jay W., Amerada Petr. Corp., 306 Kerr-McGee Bldg., Oklahoma City, Okla.
‖Clark, Walter Thomas, Jr., Standard Oil Co. of Texas, Dallas, Tex.
‖Clarkson, Francis Richard, United Carbon Co., Box 1913, Charleston, W. Va.
Claudet, Aime P., Schlumberger Well Surveying Corp., 451 Canal Bldg., New Orleans, La.
‖Cliff, Murray Joseph, Pure Oil Co., Box 1398, Billings, Mont.
Cokinos, Geneos Pete, Texas Railroad Commission, Beaumont, Tex.
‖Cole, Thomas H., Honolulu Oil Corp., Box 1391, Midland, Tex.
Comstock, William S., Franco Western Oil Co., 601 Edison Bldg., 601 W. Fifth St., Los Angeles, Calif.
‖Conybeare, Charles Eric Bruce, State College of Washington, Box 205, College Sta., Pullman, Wash.
Coon, Lester Alfred, The Texas Co., Canal Bldg., New Orleans, La.
Cooper, Gustav Arthur, U. S. Natl. Museum, Washington, D. C.
‖Cooper, Jack Charles, Continental Oil Co., Lakewood, Colo.
Corps, Edward Victor, Burmah Oil Co., Ltd., Main St., Upper Assam, Digboi, India
‖Cox, John Rowland, The Texas Co., Wichita, Kan.
‖Crawford, John William Roy, III, The California Co., Denver, Colo.
‖Cross, Robert Henderson, Creole Petr. Corp., Apt. 889, Caracas, Venezuela, S. A.
‖Crouse, Hubert Yates, Carter Oil Co., Box 43, Rawlins, Wyo.
Culbertson, James A., Colombian Petr. Co., Apt. 100, Cucuta, Colombia, S. A.
‖Curtis, Malcolm Rex, 2021 S. Josephine St., Denver, Colo.
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PITTSBURGH REGIONAL MEETING, OCTOBER 4–9, 1948

FINAL ANNOUNCEMENT

Plans for the meeting and field trip are nearly completed.
Have you mailed the *Postal Card* to make your hotel reservations?

SPECIAL NOTICE CONCERNING THE FIELD TRIP

Transportation will be by chartered Greyhound Bus with a police escort. A guide in each bus will discuss the geology as the caravan proceeds. Private cars will not be allowed in the caravan. The buses will start at Pittsburgh, Pa., and return to Pittsburgh, Pa.

A REGISTRANT FOR THE TRIP MAY ELECT ONE OF THE FOLLOWING OPTIONS IN ORDER TO FACILITATE HIS RETURN TRIP HOME

(1) Bus transportation from Pittsburgh, Pa., to Buffalo, N. Y. Leave the bus at Buffalo Friday afternoon. Proceed to destination via selected means of transportation at own expense.
(2) Bus transportation from Pittsburgh, Pa., to Buffalo, N. Y., and return to Pittsburgh Friday afternoon in one of the chartered buses.
(3) Bus transportation for field trip and conference on secondary recovery at Bradford, Pa. Return by chartered bus to Pittsburgh Saturday afternoon.

Please be prepared to state the transportation option you desire at the time of registration. The cost of the trip will depend on the option selected.

HOTEL WILLIAM PENN—HEADQUARTERS

ANNOUNCEMENT

A mid-year regional meeting of the American Association of Petroleum Geologists will be held in Pittsburgh, Pennsylvania, October 4–9, 1948. Members of the Pittsburgh Geological Society, which is acting as host society, are endeavoring to provide an attractive technical session and field trip which will make this meeting worth while. The general theme of the meeting will be "Appalachian Geology." A cordial invitation is extended to all A.A.P.G. members.

HOTEL RESERVATIONS

A postal card which was recently mailed should be returned to make your room reservations at the Hotel William Penn. Reservations should be made directly with the hotel and not with a committeeman.

COSTS

The registration fee is tentatively set at $5. This will assist in defraying the cost of putting on the meeting. The total cost of the entire field trip, including transportation, guide book, plus meals and hotels probably will not exceed $70.

GENERAL OUTLINE OF PROGRAM

Monday, October 4	—Registration and technical session on 17th floor of Hotel William Penn
Night	Banquet and paper on Philosophy of Research
Tuesday, October 5	—Technical session
Night	Nothing scheduled at present
Wednesday, October 6	—First day of field trip, Pittsburgh to Harrisburg, Pa.
Thursday, October 7	—Field trip, Harrisburg, Pa., to Rochester, N. Y.
Night	Buffet supper for the group
Friday, October 8	—Field trip, Rochester, N. Y., to Niagara Falls and Buffalo. End of field trip except for those electing secondary recovery conference
Night	Banquet at Bradford, Pa., and paper on Secondary Recovery
Saturday, October 9	—Field inspection of the Bradford area, return to Pittsburgh Saturday afternoon

TECHNICAL SESSIONS

(Tentative program. Papers may be added, deleted, or the order may be revised)

MONDAY, OCTOBER 4 (MORNING)

1. General orientation paper reviewing geology and production of the Appalachian area, by R. E. Sherrill
2. Petrology and paleogeology of the Greenbrier limestone, by Gordon Rittenhouse
3. The Hemlock Grove Berea Sand pool, Meigs County, Ohio, by R. L. Alkire
4. The Fifth Sand pool (formerly known as McDonald and Robinson), Allegheny and Washington counties, Pa., by A. I. Ingham

(AFTERNOON)

A series of papers on the geology and occurrence of natural gas in the Oriskany sand of the Appalachian area.

5. Part A. The occurrence in faulted anticlines with particular reference to the Ellisburg, Harrison, and Woodhull trend, by F. H. Finn
6. Part B. The occurrence in low relief domes with particular reference to pools in South Beaver Township, Beaver County, Pa., and in Knox Township, Columbiana County, Ohio, by John T. Galey
7. Part C. Stratigraphic accumulation in the Cambridge area, Gurnsey and Tuscarawas counties, Ohio, by J. R. Lockett
8. Part D. Stratigraphic accumulation in the Jackson-Kanawha counties area of West Virginia, by A. H. McClain

(EVENING). Banquet

9. The philosophy of research, by E. R. Weidlein

TUESDAY, OCTOBER 5 (MORNING)

10. Geology and occurrence of natural gas in the Newburg horizon, Mayfield Township, Cuyahoga County, Ohio, by H. R. Rothrock
11. Some phases of oil and gas geology of the Ontario Peninsula, by W. A. Roliff
12. Geology and occurrence of oil in the Medina sand of the Blue Rock-Salt Creek, Ohio, pool, by James F. Swain
13. Geology and occurrence of oil in the Rose Hill area of Lee County, Virginia, by Byron Cooper
14. Results of studies of Silurian rocks east of the Allegheny Front in Pennsylvania, by Frank Swartz

(AFTERNOON)

15. Results of studies of Ordovician rocks east of the Allegheny Front in Pennsylvania, by C. E. Prouty

(Papers 14 and 15 will include a reference to reservoir rocks that are contained in these members)

16. Facies change in the Appalachian basin from west to east, by R. E. Bayles
17. Relationship of magnetic anomalies to surface structure east of the Allegheny Front in Pennsylvania, by H. R. Joesting and J. R. Balsley
18. Evolution of thought on Appalachian structure from Rogers to the present, by John Rodgers
19. Structure of the Basement complex of the Appalachian area, with particular reference to Pennsylvania, by Ernst Cloos

(EVENING)

20. Nothing scheduled at present

FRIDAY, OCTOBER 8 (EVENING). Dinner Meeting at Bradford, Pa.

21. The geological factors involved in secondary recovery, by Maynard M. Stephens

FIELD TRIP

SUMMARY OF ITINERARY

WEDNESDAY, OCTOBER 6

Pittsburgh to Harrisburg, about 215 miles. Pittsburgh to Turnpike entrance on Route 30. Turnpike to Somerset. Somerset to Stoystown on Route 53. Stoystown to Bedford on Route 30. We plan to leave the Turnpike at Somerset in order to stop at Grand View Point on the Allegheny Front. This is an excellent vantage point from which to view the physiography and geology of the western part of the Ridge and Valley Province, and will probably be a major stop of the day. Bedford to Middlesex on Turnpike. Middlesex to Harrisburg on Route 11. A. B. Cleaves' work along the Turnpike will be used.

Overnight stop in Harrisburg. Accommodations have been reserved at the Penn, Harris, and the Harrisburger hotels.

No banquet or group dinner is being planned in Harrisburg.

THURSDAY, OCTOBER 7

Group breakfast in Harrisburg.

Harrisburg to Rochester, New York, about 260 miles. Harrisburg to Sunbury on Route 14. Sunbury to Cohocton, N. Y., on U. S. Route 15. Cohocton to Canandaigua on Routes 371, 245, and 21. Canandaigua to Rochester on Routes 332 and 96. Bradford Willard has logged the Pennsylvania part of this trip. John G. Broughton and staff from the New York State Science Service are working on the New York part of the trip. Overnight stop in Rochester at the Sheraton Hotel. A buffet supper has been offered for the group by the Bausch and Lomb Optical Company. Arrangements are being made to have the Rochester Museum open for the delegates. Interesting geological displays are exhibited there. It is possible that some of Rochester's industries will have exhibits also.

FRIDAY, OCTOBER 8

Group breakfast in Rochester at the Sheraton Hotel

Geology of Rochester Gorge

Rochester to Niagara Falls on Route 104, about 85 miles

Geology of Niagara Gorge

Devonian-Silurian unconformity in limestone quarry near Buffalo. For those who do not go to Bradford, this will be the end of the trip.

In order to provide the necessary facilities at this point, the following information must be acquired at registration time

1. Those going to Bradford
2. Those requiring transportation from Buffalo directly to Pittsburgh on Friday afternoon

There will probably be no stops between Rochester and Niagara Falls, but the route will be logged. From Niagara Falls to Bradford, the log follows Route 16, and there may be a short stop at Rock City if time permits. It is about 115 miles from the Falls to Bradford on this route.

The caravan should be in Bradford in time for the evening banquet.

SATURDAY, OCTOBER 9

Inspection of oil fields in the Bradford area. Return to Pittsburgh.

PITTSBURGH GEOLOGICAL SOCIETY
OFFICERS, 1948–1949

President: John T. Galey
Vice-president: W. B. Robinson
Treasurer: S. S. Galpin
Secretary: J. C. Patton

COMMITTEE CHAIRMEN

General: H. R. Brankstone
General arrangements: Shailer S. Philbrick
Program: John T. Galey
Field-trip: George C. Grow
Finance: S. S. Galpin
Publicity: W. B. Robinson

WEST TEXAS GEOLOGICAL SOCIETY FIELD TRIP, OCTOBER 29–31, 1948

A field conference sponsored by the West Texas Geological Society is scheduled for October 29, 30, and 31, in the Big Bend region of southwest Texas. The specific areas to be studied are: Green Valley, Solitario, Limpia Canyon, and the Barilla Mountains. The purpose of this conference is to study Upper Cretaceous and Tertiary rocks, the geologic

history of which is represented by a complete gap in the Permian basin. This conference should be of special interest to Gulf Coast geologists as it will afford the opportunity of examining beds contemporaneous with Gulf Coast producing strata.

The geological studies for this conference were made by the Texas Bureau of Economic Geology.

FIRST DAY.—Green Valley and Paradise Valley—Led by Professor S. S. GOLDICH, University of Minnesota, and CLAY SEWARD, Texas Bureau of Economic Geology.

SECOND DAY.—Solitario—Led by Professor S. S. GOLDICH; JOHN T. LONSDALE, director of Texas Bureau of Economic Geology; and RONALD K. DEFORD, Argo Oil Corporation, Midland, Texas.

The Solitario shows the southwest extension of the Marathon facies of Paleozoic rocks with their sharp Appalachian-type folding and overthrusting. JOHN T. LONSDALE will discuss aspects of the igneous geology of the Solitario.

THIRD DAY.—Davis and Barilla mountains—Led by Professor G. K. EIFLER, JR., department of geology, University of Texas.

Hotel reservations should be made through NUGENT T. BRASHER, chairman of the hotel committee, Box 1540, Midland, Texas. All reservations *must* be made through the hotel committee. Due to limited hotel facilities participants should select roommates. The hotel committee finds it necessary to limit accommodations to actual conference participants.

Assembly and registration will be carried out under the direction of CLYDE W. TURNER and JANE MARIE JOHNSON, registration committee, at Marfa, Texas, Thursday night, October 29.

Attention is invited to the following notes regarding the conference. Roads have been improved throughout the Big Bend region; however, use of shorter wheel-base cars such as Fords, Chevrolets, and Plymouths, is recommended. To accompany the caravan for the first two days of the trip the Casner Motor Company at Marfa, Texas, is furnishing a wrecker which will be on hand to cope with "flats," mechanical difficulties, *et cetera.*

All participants are to provide their own drinking water and are urged to provide an ample supply.

The West Texas Electrical Log Service is publishing the guidebooks under the supervision of MAX DAVID, Midland, Texas, and H. LEE PIERCE, Dallas, Texas.

Additional information concerning the conference may be obtained by writing RONALD K. DEFORD, general chairman of the field conference, Argo Oil Corporation, Box 1814, Midland, Texas, or C. H. ATCHISON, chairman of the publicity committee, Honolulu Oil Corporation, Box 1391, Midland, Texas.

HOUSTON REGIONAL MEETING, DECEMBER 2–3, 1948

A regional meeting of the Association will be held in Houston, Texas, on December 2 and 3, 1948, at the invitation of the Houston Geological Society. A. F. CHILDERS, president of the Society, has announced appointment of the following committees and chairmen to have charge of arrangements.

General committee—GEORGE S. BUCHANAN, Sohio Petroleum Company

Technical program—HILLARD W. CAREY, Houston Natural Gas Corporation

Hotels and housing—CARLETON D. SPEED, JR., Speed Oil Company, 1315 Second National Bank Building

Finance—E. O. BUCK, National Bank of Commerce

Entertainment and dance—DONALD I. GAHAGAN, Pan American Producing Company

Publicity-program—J. BRIAN EBY, consultant, 1404 Esperson Building

Registration—FRANK J. GARDNER, Rinehart Oil News Company

Program—PAUL B. LEAVENWORTH, Gulf Oil Corporation

(The following is a copy of the announcement to be mailed to all members)

ANNOUNCEMENT

REGIONAL MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Rice Hotel, Houston, Texas, December 2–3, 1948

A regional meeting of the American Association of Petroleum Geologists will be held at the Rice Hotel, Houston, Texas, on December 2 and 3, 1948.

For your convenience in making hotel reservations for the coming regional meeting of the American Association of Petroleum Geologists, in Houston, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second, and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if your request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED MUST BE INCLUDED.

Hotel	*One Person*	*Two Persons*		*2-Room Suites*
		Double Bed	*Twin Beds*	*Parlor and Bedroom*
RICE	$4.00 to $7.00	$5.00 to $8.00	$6.00 to $9.00	$15.00
LAMAR	$3.50 to $5.00	$5.00 to $7.00	$6.00 & $7.00	$12.00 to $15.00
BEN MILAM	$3.00 to $6.00	$4.00 to $8.00		
SAM HOUSTON	$2.25 to $3.50	$3.25 to $4.50		
WM. PENN	$2.75 to $4.25	$4.25 to $5.75		
TEXAS STATE	$3.00 to $9.00	$5.50 & up		

In the event that the hotel room-rate structure is changed prior to the meeting these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED BY NOVEMBER 15, 1948.

American Association of Petroleum Geologists, Hotel Reservations, Bruce Carter, Rice Hotel, Houston, Texas.

Please reserve the following accommodations for the regional meeting of the A.A.P.G. in Houston, Texas, on December 2 and 3, 1948.

Single Room..... Double-Bedded Room..... Twin-Bedded Room.....

2-Room Suite..... Other Type of Room.....

Rate: From $..... to $.....First choice hotel.....

Second choice hotel.....

Third choice hotel.....

Arriving at Hotel (date)..... Hour .....A.M. .....P.M. .....

Leaving Hotel (date) ..... Hour .....A.M. .....P.M. .....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin-bedded room requested. Names and addresses of all persons for whom your are requesting reservations and who will occupy the rooms asked for:

.....

.....

(Individual requesting reservations)

Name..... Address..... City & State.....

If the hotel of your choice is unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere provided all hotel rooms have not been taken.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 9 (SEPTEMBER, 1948), PP. 1849-1850

MEMORIAL

ALFRED RAAB EYSSELL
(1898–1944)

Alfred Raab Eyssell died of heart failure in Vallejo, California, June 28, 1944. Interment was in Kansas City, Missouri.

Al was born, April 14, 1898, in Kansas City, Missouri. He attended the University of Pennsylvania for the two years prior to the first World War. From February 26, 1918, to July 30, 1919, he was in the Field Artillery and served one year overseas, part of this time in active combat. On his release from the Army, he entered the University of Pittsburgh and was graduated with high honors in June, 1923, as a petroleum engineer. During his college days he was elected to membership in Sigma Alpha Epsilon and Sigma Gamma Epsilon fraternities.

On January 10, 1925, he married Carolyn Douglas Clark, in Pittsburgh, Pennsylvania. Two children were born of this marrigae, Carolyn Christene, now 19 years old, and James Hugh, now 16 years of age. The widow and children, now of Glenshaw, Pennsylvania, and a sister, Mrs. Eloise E. Bergmann of Los Angeles, California, survive him.

His professional career began in 1923 with his employment by the Peerless Oil and Gas Company. He rapidly rose to be vice-president in charge of the land and geological departments for Texas and New Mexico, with headquarters in San Angelo, Texas. The last few years of his association with Peerless were spent in San Antonio, Texas. In 1936 he accepted a position with the Louisiana Land and Exploration Company, which he held until 1939. World War called him again to the Army and on November 21, 1942, he entered the Coast Artillery with the rank of First Lieutenant and served until March 3, 1944. In less than four months, death closed his successful and promising career.

It was my pleasure and good fortune to work for Al for many years—my pleasure, because he was able to make work pleasant and interesting for all his employees, and because he maintained a spirit of strong guidance in business relationship together with close friendship and informal association—my good fortune, because he had a remarkably penetrating intellect that he did not mind sharing with others, and because he had the rare gift of combining his scientific and technical knowledge with hard-bitten business acumen to produce the results needed in the search for oil.

Al Eyssell was a loving son, husband, and father, a true friend, a grand companion, and a real man. Countless friends and associates will agree that the Association has lost a valuable member and a good American.

H. H. HENDERSON

San Antonio, Texas
July 13, 1948

EDWIN LEIGHT PORCH, JR.
(1889–1948)

On June 9, 1948, Edwin Leight Porch, Jr., consulting geologist of San Antonio, Texas, died in the Nix Hospital in San Antonio.

Edwin, son of Edwin Leight, Sr., and Nina Dortch Porch, was born at Kisseems, Florida, on June 19, 1889. He graduated from Bell High School in Galveston, Texas, in 1906. The following year his parents moved to San Antonio and Ed attended the University of Texas during the term of 1906–1907. The following three years he attended the

Michigan College of Mines at Houghton, Michigan, and received his B.S. and Engineer of Mines degrees from that school in 1911.

The following year Ed was employed as a mining engineer for the Espada Mines Company in the state of Jalisco, Mexico, and when the revolutionaries made it impossible to continue mining operations in that part of Mexico, he entered the University of Texas as a special student, taking courses in technology of fuels and in electrical engineering during the year 1912–1913. The next year was spent on various projects and from June, 1914, to July, 1917, he was employed by the Texas Bureau of Economic Geology.

World War I interrupted Ed's professional work and he was in the Air Corps from July, 1917, until March, 1919, as an instructor. He received his pilot's wings in 1918 and was discharged as a First Lieutenant.

Following army service, the next two years were spent in San Antonio as a consultant and from April, 1921, to December, 1923, Ed was employed by "El Aguila" and held the position of acting assistant chief geologist in Tampico, Mexico.

After the termination of this second tour in Mexico, and until his death, Ed was engaged primarily as a consulting geologist with offices in San Antonio, making many trips to Mexico for various clients to examine mineral properties and prospects, both oil and mining. Most of his work, however, was in Texas, Louisiana, and New Mexico.

Ed was the author of the University of Texas *Bulletin 1722*, "The Rustler Springs Sulphur Deposits" (1917) and he compiled or assisted in compiling data used in the publication of University of Texas *Bulletin 35*, "The Fuels Used in Texas (1915), *Bulletin 44*, "Review of the Geology of Texas" (1916), *Bulletin 1814*, "Chemical Analysis of Texas Rocks and Minerals" (1918), *Bulletin 1839*, "Road Building Materials in Texas" (1919), and *Bulletin 1932*, "The Geology and Mineral Resources of Bexar County" (1920).

He was a member of the American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, South Texas Geological Society, and the Society of Economic Paleontologists and Mineralogists, and a fellow of the American Association for the Advancement of Science, and honorary member of Sigma Gamma Epsilon. He was a member of the Sons of The American Revolution. His primary interests were scientific as reflected by his extensive library and his many activities in the South Texas Geological Society, of which he was a charter member.

Ed was always willing to lend a helping hand, particularly to younger members of his profession. He had a cheerful disposition and his innate love for his fellow man was reciprocated by a wide circle of friends that loved and respected him in turn. Those who knew him best had the greatest respect for his scientific mind and ability.

EDWARD LEE JOHNSON

San Antonio, Texas
August 3, 1948

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Monthly meetings. Visiting geologists are welcome.

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Sun Oil Company, Box 717

Meetings will be announced.

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Stanolind Oil and Gas Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

LOUISIANA

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NEW ORLEANS, LOUISIANA

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Vice-President and Program Chairman - - -
- - - - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Secretary-Treasurer - - - - - Ame Vennema
Schlumberger Well Surveying Corporation

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Barnsdall Oil Company
427 Ricou-Brewster Building
Vice-President - - - - Walter F. Hamilton
Gulf Refining Company
Box 1731
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Schlumberger Well Surveying Corporation
Box 92

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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Secretary - - - - - - - - - H. L. Tipsword
Magnolia Petroleum Company, Box 872
Treasurer - - - - - - - - - Philip R. Allin
Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Business Manager - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

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Vice-President - - - - - - - Carl F. Grubb
Superior Oil Company
Secretary-Treasurer - - - - - E. T. Monsour
Consultant, Box 2571, West Jackson

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

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Vice-President - - - - - Richard G. Kendall
The California Company, Box 153
Secretary-Treasurer - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - Robert R. Wheeler
Consultant, 1216 Petroleum Building
Vice-President - - - - - - L. R. Wilson
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1300 Apco Tower
Secretary - - - - - - - - - John Janovy
Tide Water Associated Oil Company,
918 Hales Building
Treasurer - - - - - - - - Elwyn R. Owens
Phillips Petroleum Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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Vice-President - - - - - - Doyle M. Burke
The Texas Company
Box 1007, Shawnee
Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Consultant, 1510 Philtower Building
Editor - - - - - - - - - - John C. Maher
U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Student Union or Tyrrell Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
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Box 2038
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Equitable Gas Company
610 Wood St.
Treasurer - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

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Vice-President - - - - - - - - J. R. Day
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Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

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Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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DALLAS, TEXAS

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Secretary-Treasurer - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
Executive Committee - - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

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Atlantic Refining Company
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Magnolia Petroleum Company
Box 780
Secretary-Treasurer - - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - R. H. Schweers
The Texas Company
Box 1720
Vice-President - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Secretary-Treasurer - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
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Schlumberger Well Surveying Corporation
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Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

TEXAS

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Independent Geologist, 907 Staley Building

Vice-President - - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010

Secretary-Treasurer - - - Ralph H. McKinley
Panhandle Producing and Refining Company, Box 1191

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Cities Service Oil Company, Box 350

Vice-President - - - - - - - L. B. Fugitt
Stanolind Oil and Gas Company, Box 2089

Secretary-Treasurer - - - - Fred S. Alexander
Standard Oil Company of Texas, Box 2087

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Argo Oil Corp., Box 1814

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Union Oil Company of California

Secretary - - - - - - - - Clyde W. Turner
Republic Natural Gas Company, Box 1644

Treasurer - - - - - - - - Jane M. Johnson
Independent, Kerr-McGee Building

Meetings will be announced.

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268 Oakwood Road, Charleston, W.Va.

Editor - - - - - - - - - - W. T. Ziebold
Thomas Circle Road, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P.O. Box 545

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2d Vice-President (Programs) - - W. S. Knouse
Tide Water Assoc. Oil Company, Box 1708

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Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special meetings by announcement.

POSSIBLE FUTURE OIL PROVINCES OF THE UNITED STATES AND CANADA

A symposium conducted by the Research Committee of The American Association of Petroleum Geologists, A. I. Levorsen, chairman. Papers read at the Twenty-sixth Annual Meeting of the Association, at Houston, Texas, April 1, 1941, and reprinted from the Association *Bulletin*, August, 1941.

Edited by A. I. LEVORSEN

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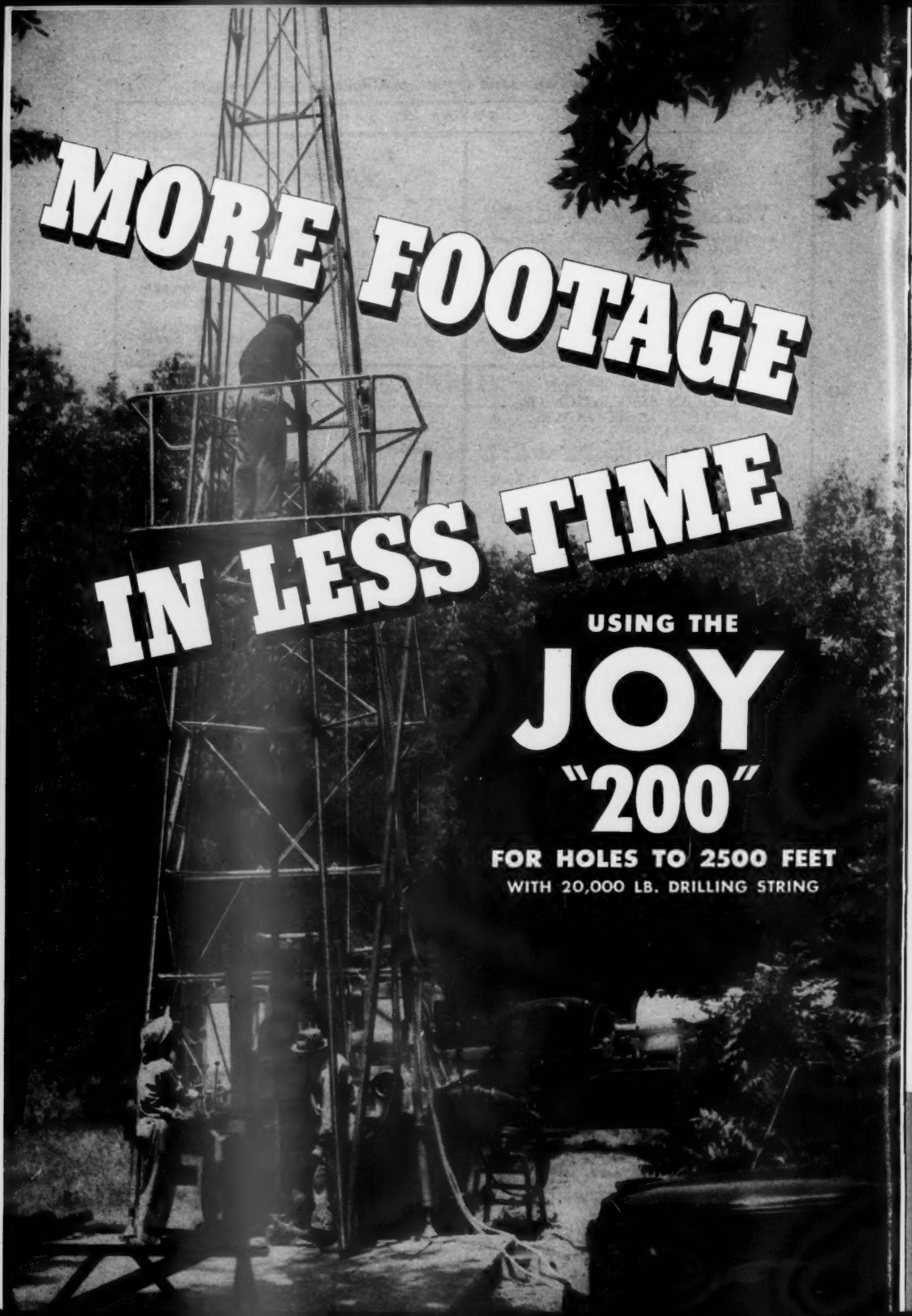
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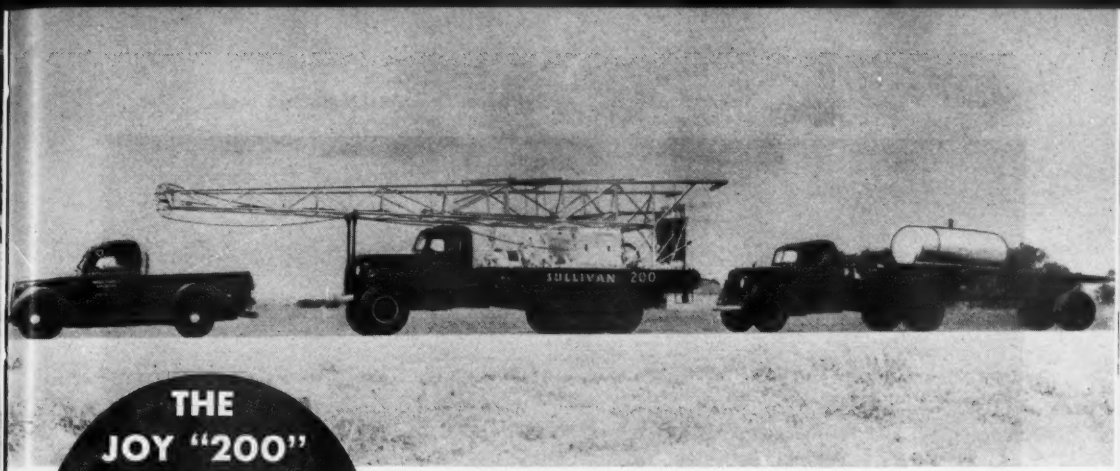

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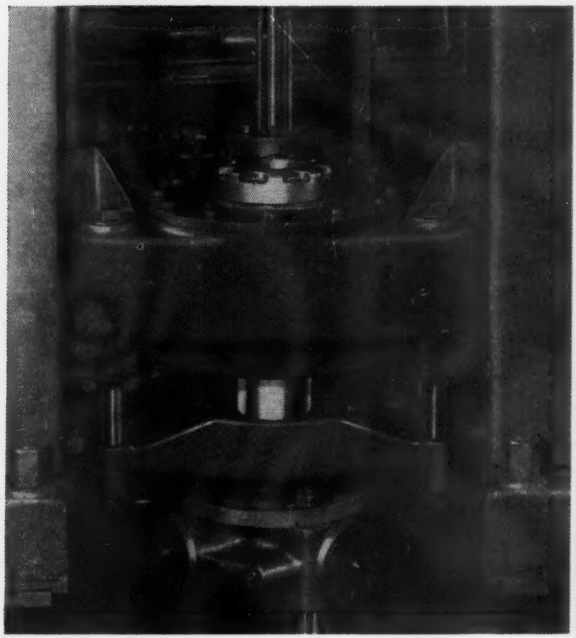

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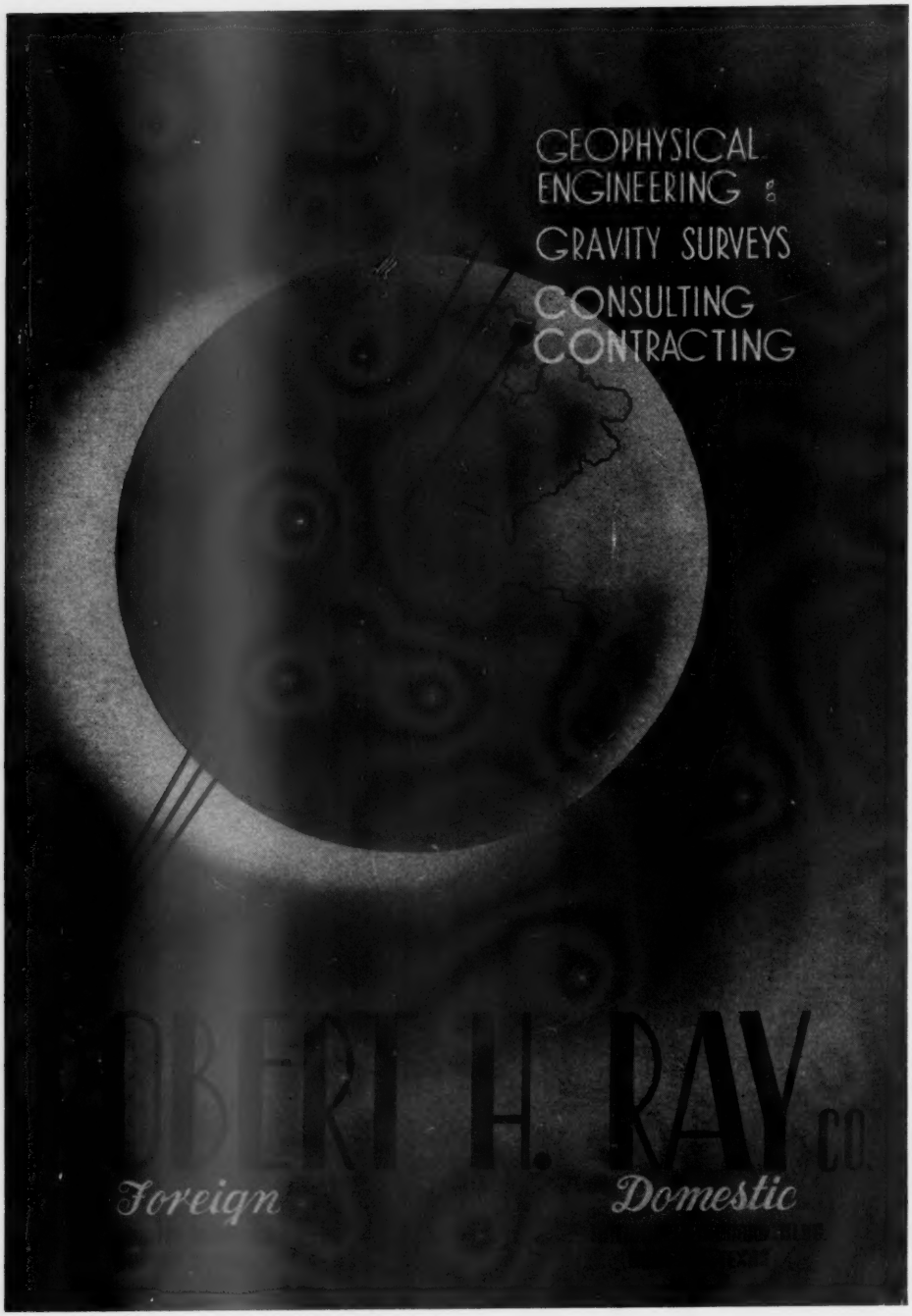
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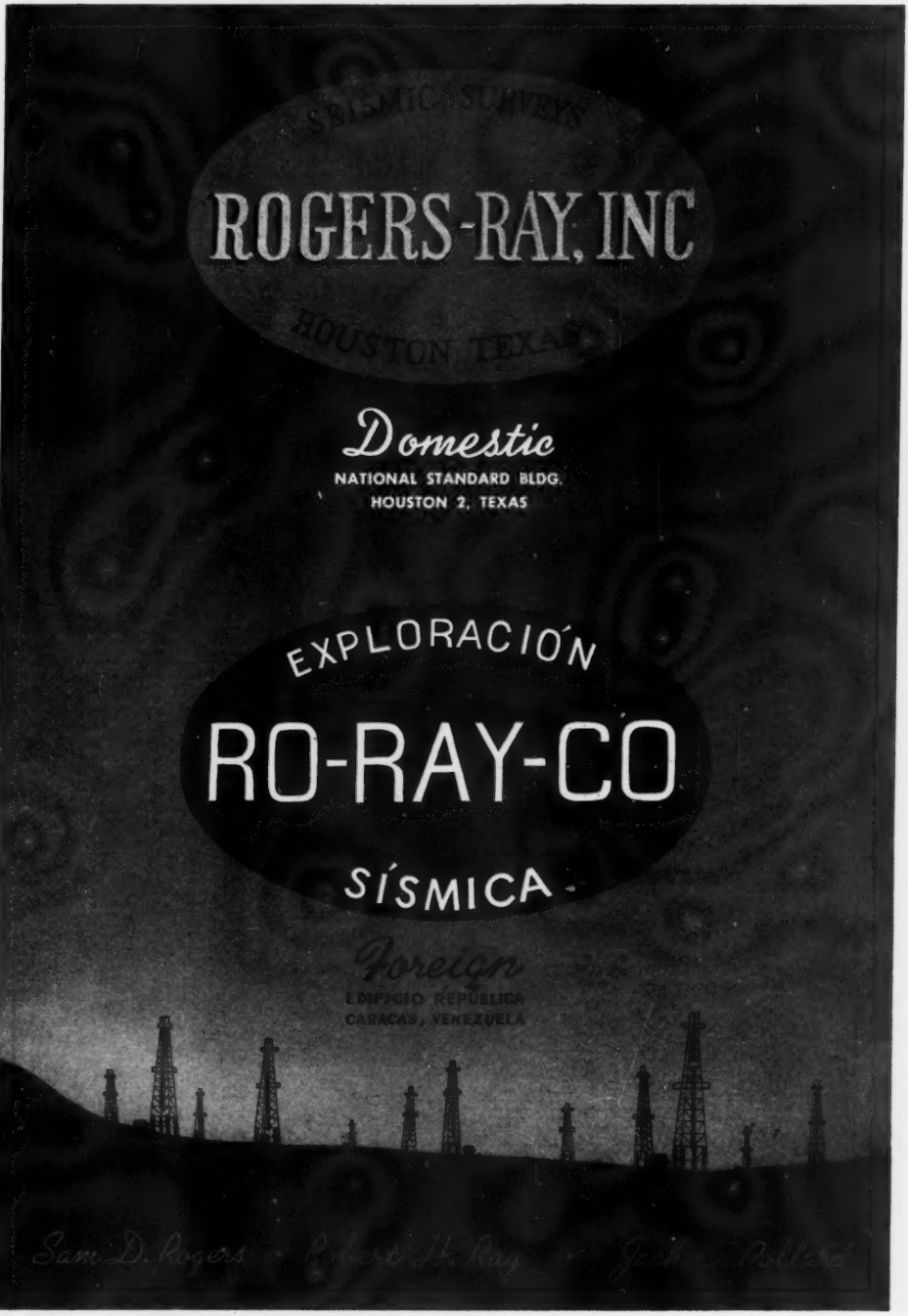
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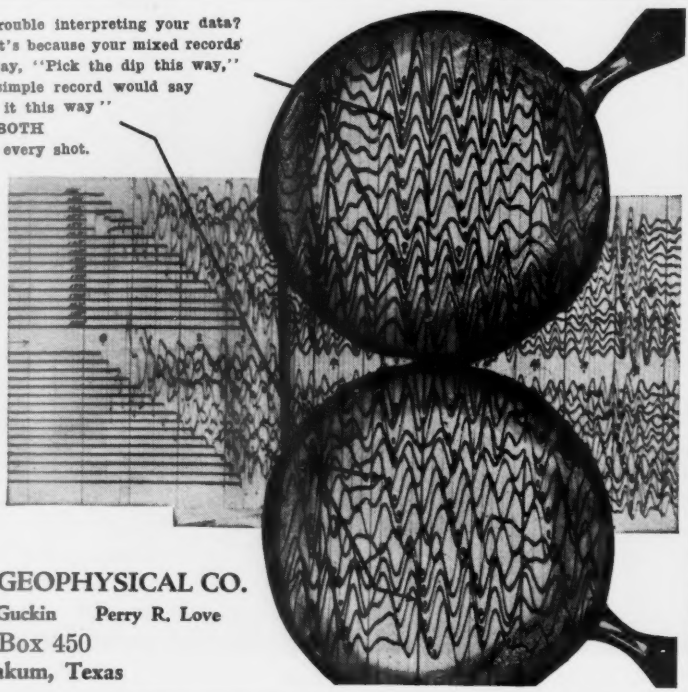

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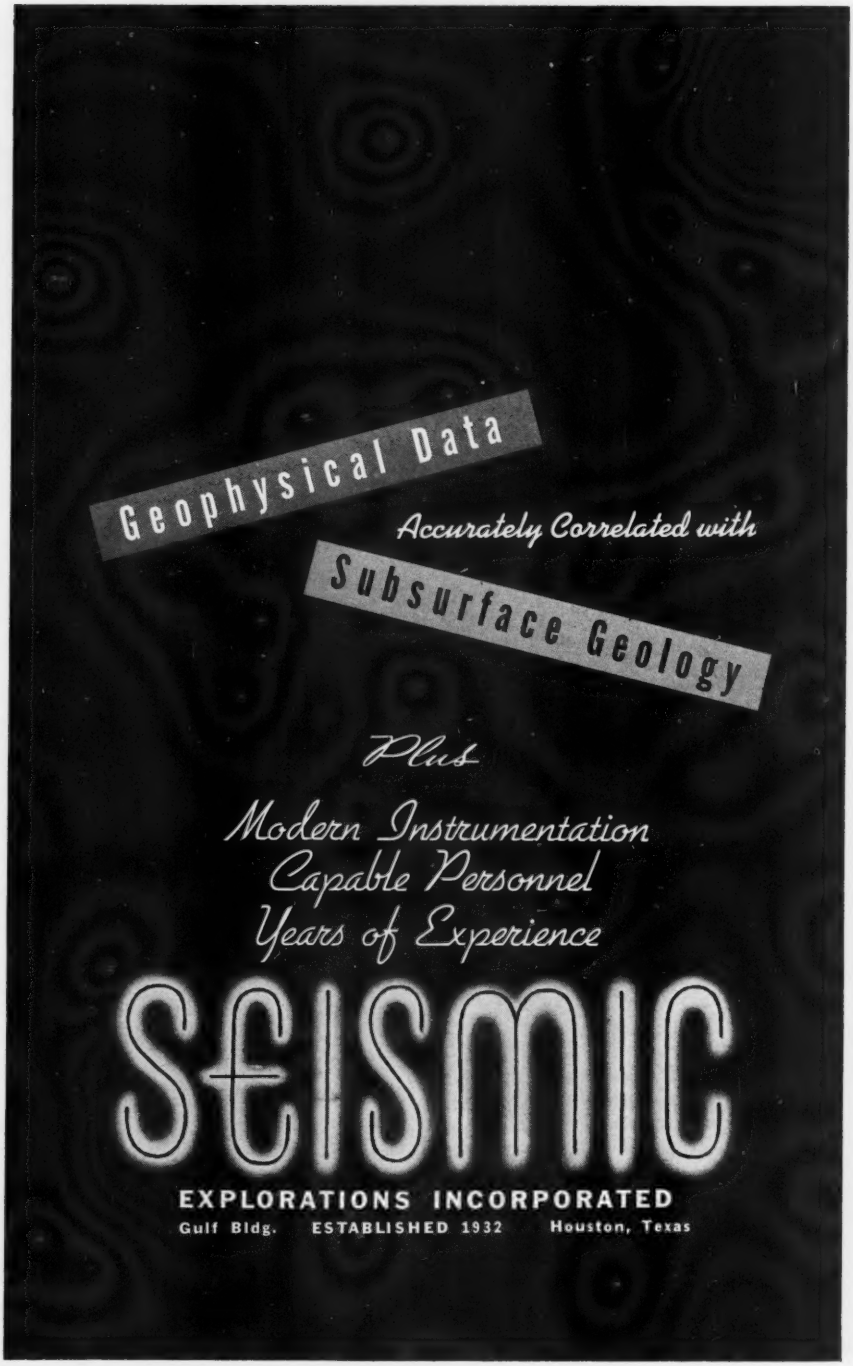
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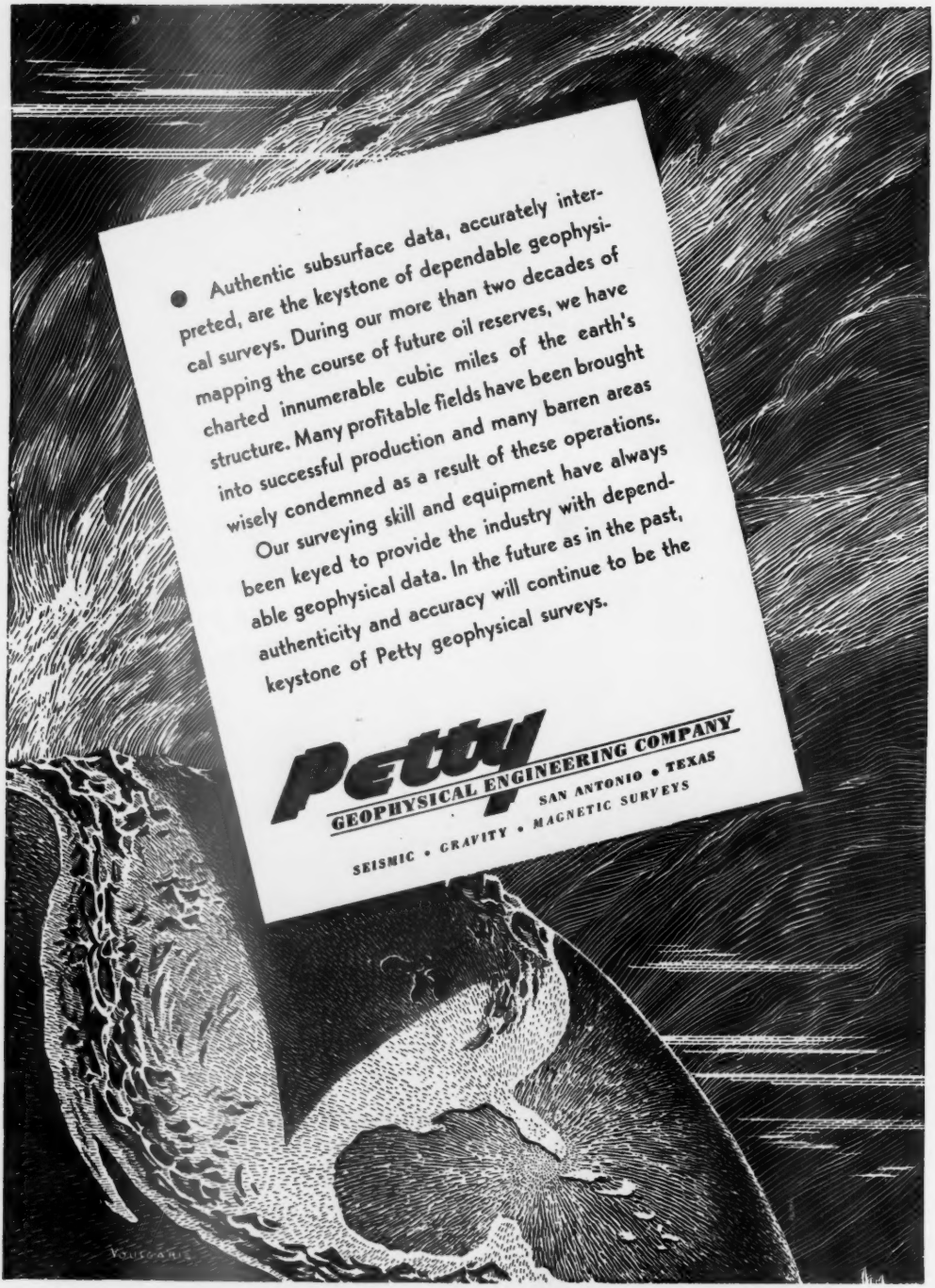
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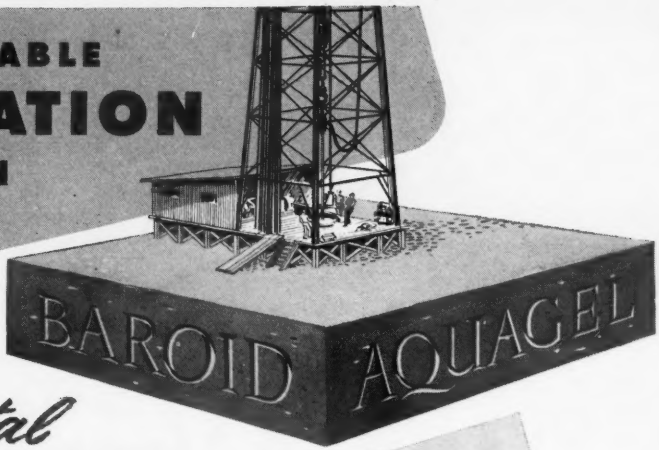

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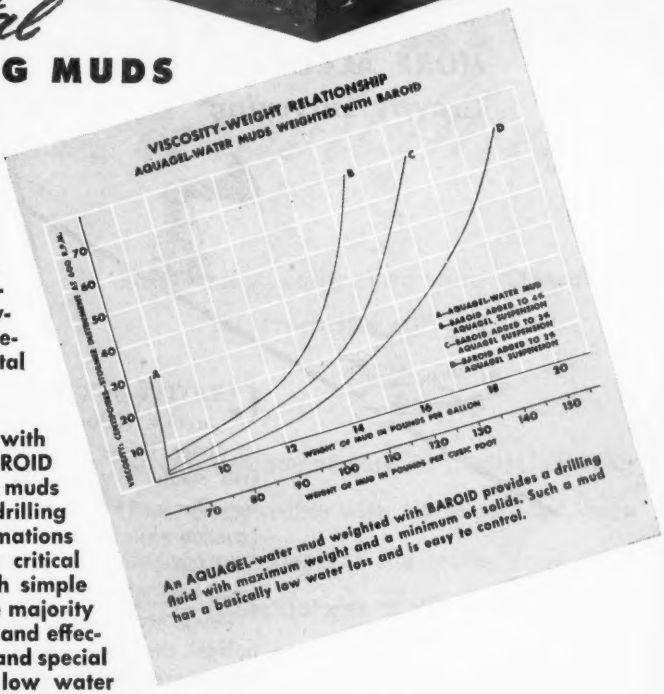

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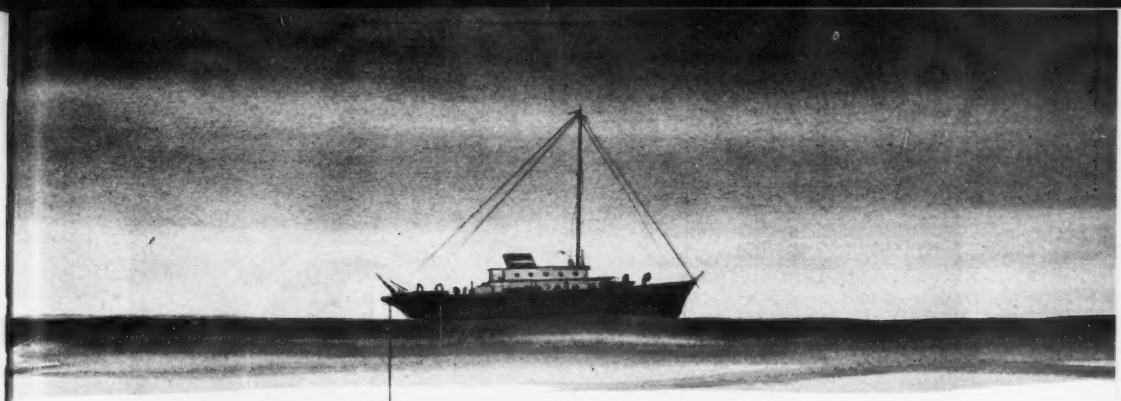

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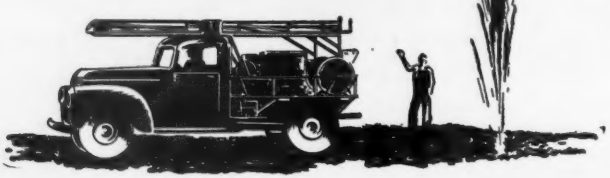

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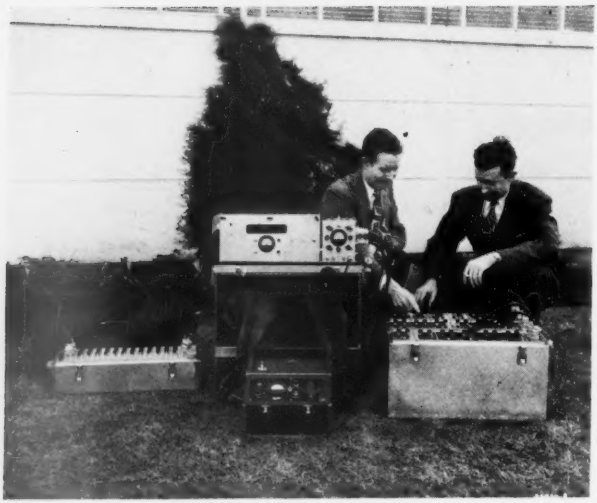

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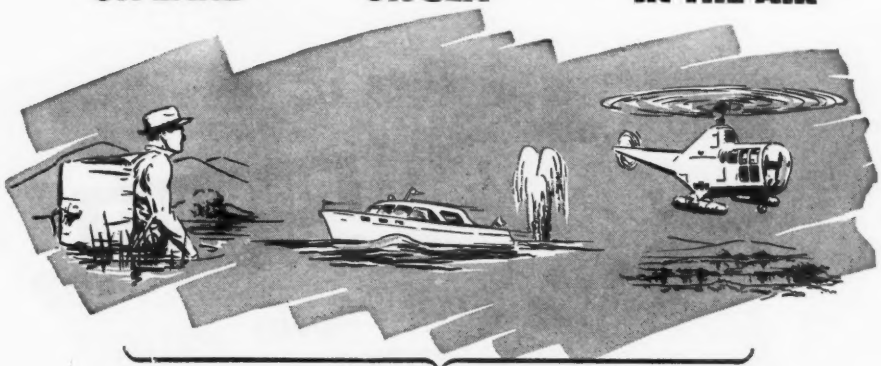

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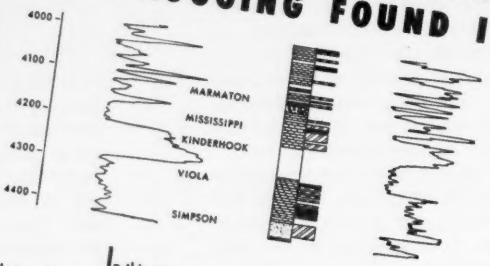

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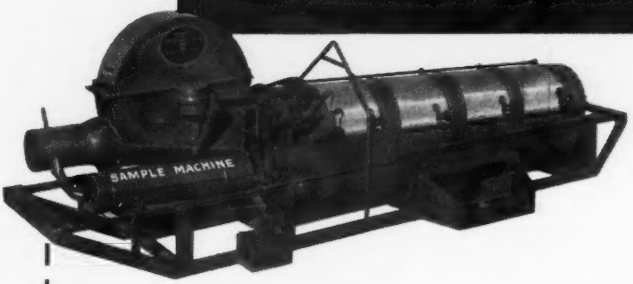

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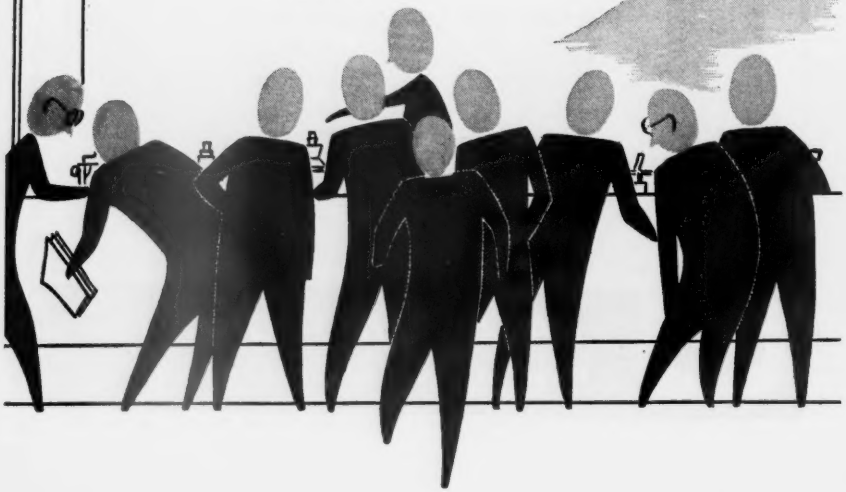

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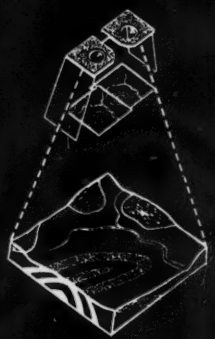

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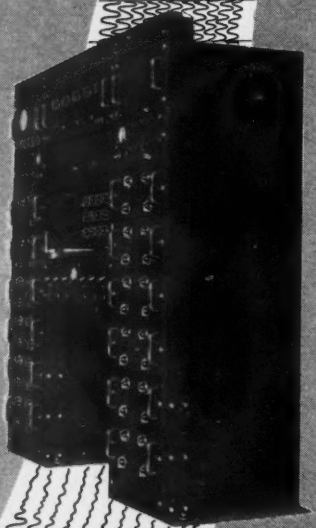

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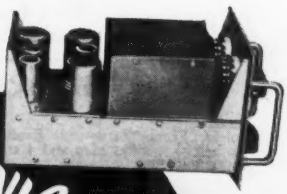

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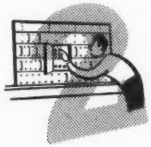

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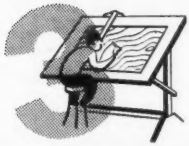

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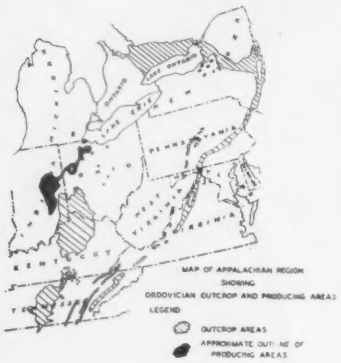

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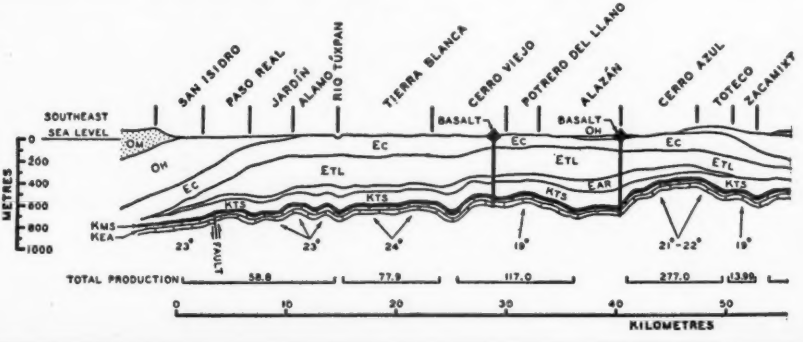

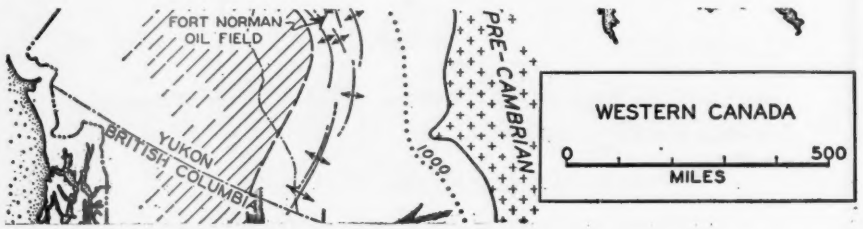

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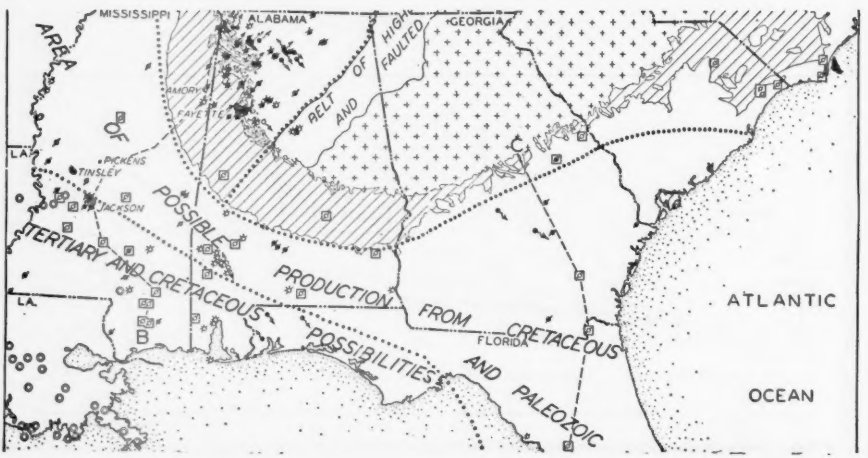

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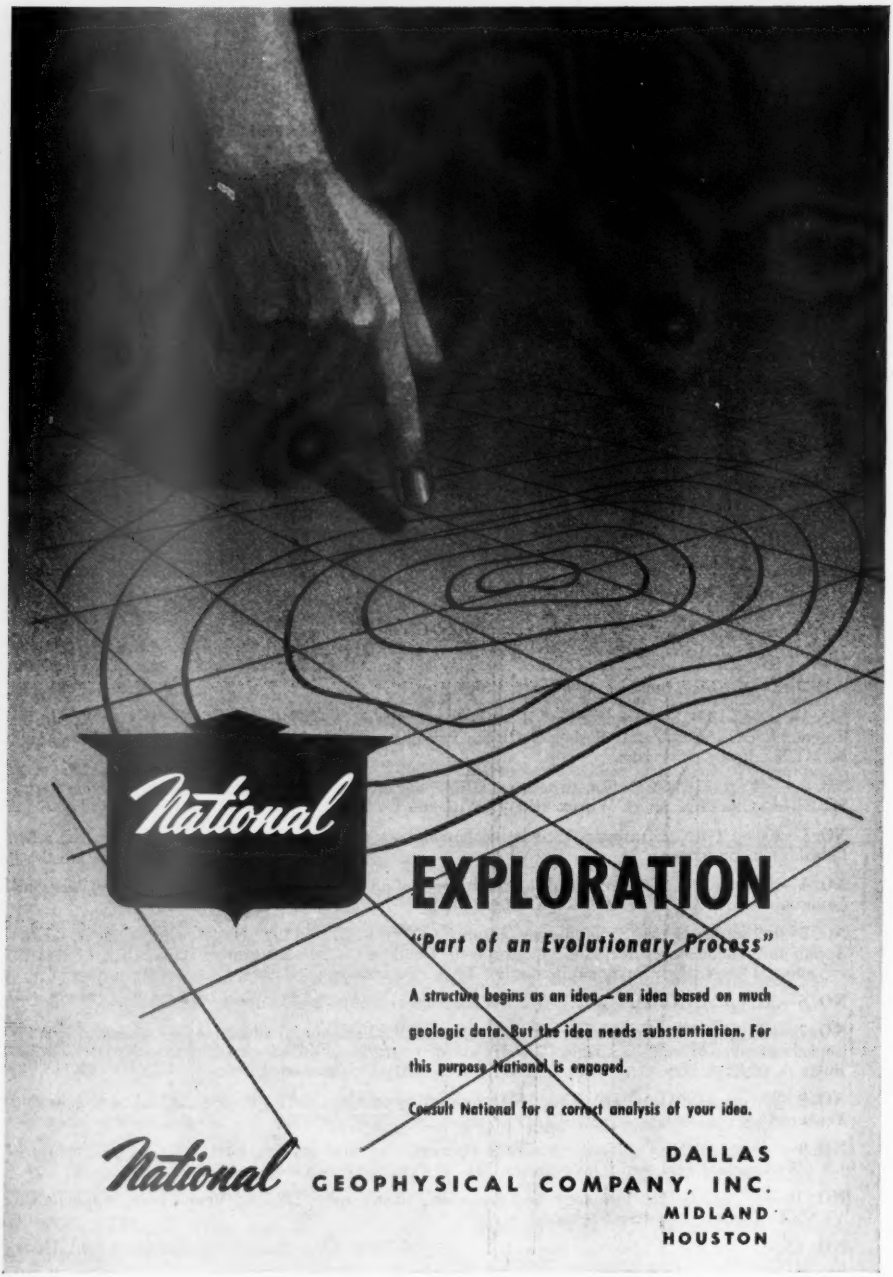
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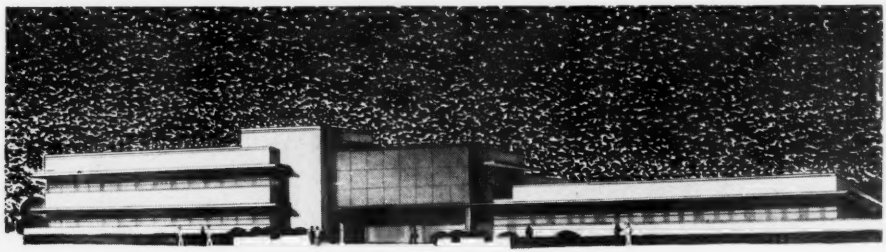

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